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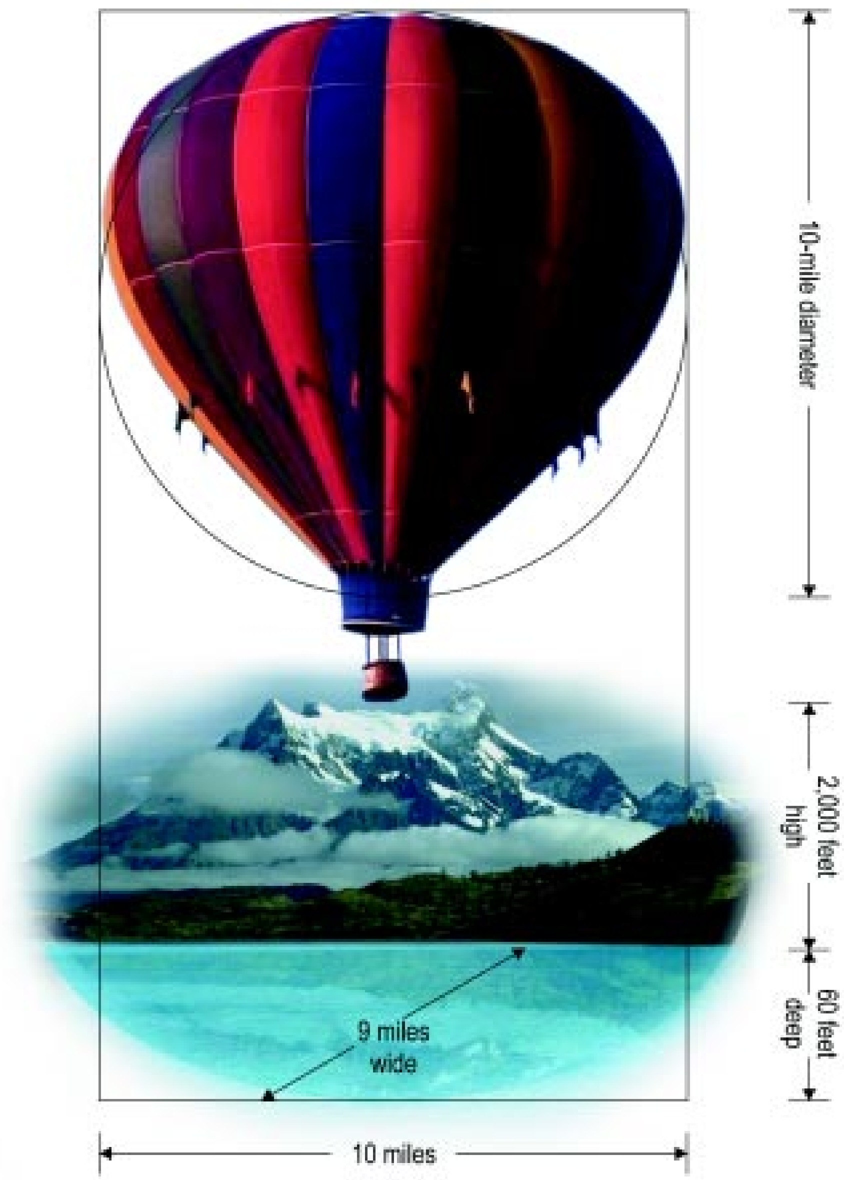

Energy Solutions for the 21st Century

U.S. DEPARTMENT OF ENERGY • OFFICE OF FOSSIL ENERGY
FEDERAL ENERGY TECHNOLOGY CENTER

Rita A. Bajura
Director, FETC

Welcome
From The Director

Welcome to the premier issue of *FETC Focus*. FETC, or the Federal Energy Technology Center, is a field office of the U.S. Department of Energy's Office of Fossil Energy. The Center is located in Morgantown, West Virginia, and Pittsburgh, Pennsylvania.

FETC's mission—*solving national energy and environmental problems*—is achieved through partnerships we forge with private industry, universities, and national labs to develop advanced energy and environmental technologies. Our interest doesn't stop there. FETC's success is measured by the private-sector acceptance of these new energy and environmental technologies that help our nation maintain a clean, affordable energy supply.

This premier issue focuses on clean energy solutions for the 21st century. There is much discussion today concerning the use of fossil fuels and the possible need to reduce greenhouse gas emissions, primarily carbon dioxide. Fossil fuels currently supply 85 percent of U.S. energy needs. At FETC, we believe fossil fuels will continue to make up a significant portion of our nation's energy mix. Our research program provides options to ensure that these fuels can be used without compromising our environment.

The advanced, high efficiency, coal- and gas-fired, power generation systems that FETC is developing will reduce electricity costs, and will use our natural resources more effectively while reducing CO_2 emissions. Developing technologies that economically recover methane hydrates also will help ensure an adequate supply of natural gas to meet U.S. demand.

This issue of *FETC Focus* shares with you a vital part of what FETC is and what we do. Future issues will give you additional insight into the only national energy technology center in the United States.

I hope you enjoy our inaugural issue of *FETC Focus*. This magazine is an important step in communicating with you, our stakeholders, and providing you with information on our ongoing activities. Your comments, questions, and suggestions for future story ideas are always welcome. FETC is also interested in your ideas on our program direction, and on the characteristics of the markets we address. As always, we look to serve you better.

Federal Energy Technology Center, Pittsburgh, Pennsylvania

Federal Energy Technology Center, Morgantown, West Virginia

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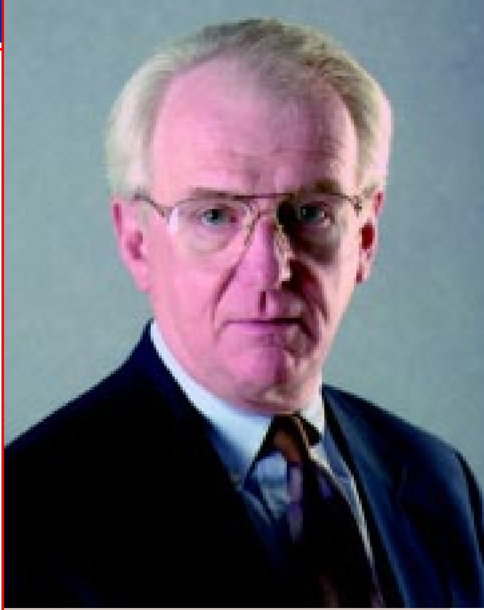
Cover photo illustrates annual world fossil-energy use—a mountain of ***coal*** 2,000 feet high and 10 miles long; a lake of ***oil*** 10 miles long, 9 miles wide, and 60 feet deep; and a balloon of ***gas*** 10 miles in diameter.



Joseph P. Strakey
Associate Director
Office of Power Systems Product Management

Energy Solutions for the 21st Century

Picture a mountain 2,000 feet high and 10 miles long. Beside the mountain is a lake 10 miles long, 9 miles wide, and 60 feet deep. Above the mountain is a giant balloon 10 miles in diameter. Every year the world uses that mountain of coal, that lake of oil, and that balloon of natural gas.

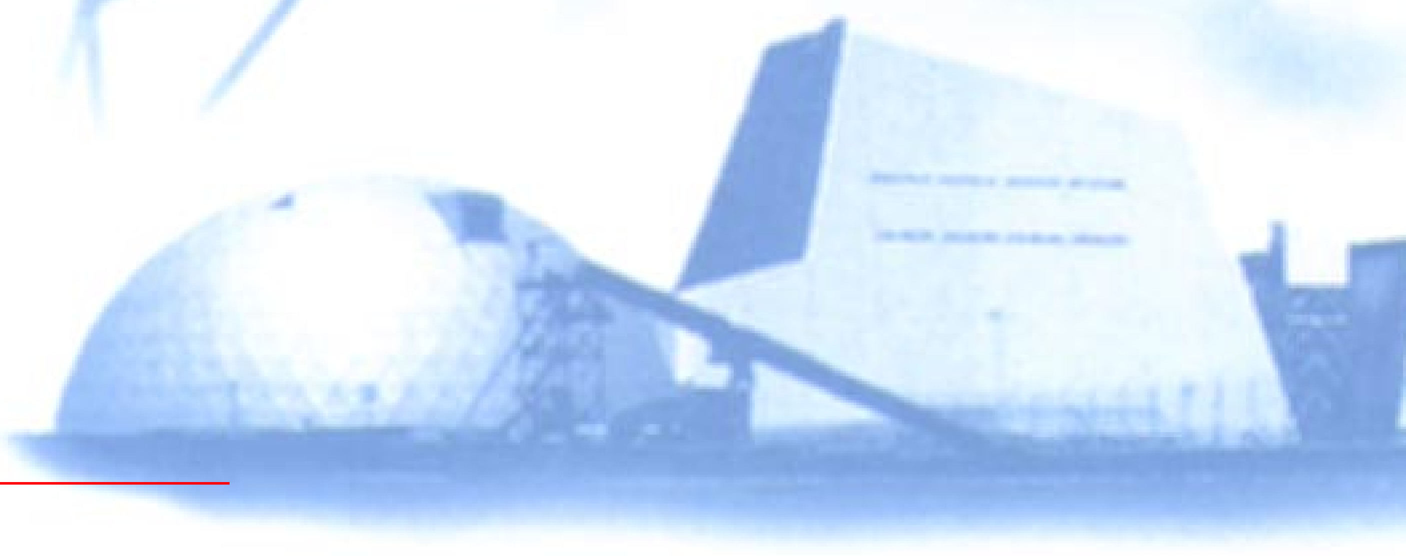
We in the U.S. use almost one quarter of that whole amount. In just over 20 years, the balloon will be 13 miles in diameter, the lake 16 miles long, and the mountain 2,700 feet high.

Will we be able to find enough gas to fill the balloon? Can we use these fuels without harming our environment? Can we extract them from the earth without environmental degradation? The answers to these questions constitute the fossil-energy mission of the Federal Energy Technology Center (FETC).

Energy is the fuel that drives our economy and allows us to enjoy our excellent standard of living. Eighty-five percent of that energy comes from fossil fuels. Supplies of fossil fuels are limited, but until cost-effective, sustainable energy sources are developed and deployed, we will have to depend on fossil fuels to sustain our way of life. While rapid advances are being made in development of sustainable energy sources, it may well take a century or more before they are deployed widely enough to largely supplant fossil fuels. FETC is developing solutions to fossil-energy supply and use issues that will ensure adequate supplies and clean use of fossil fuels in the 21st century.

Energy Supply Challenges

The U.S. has used about half of its economically recoverable supply of conventional natural gas. The demand for this clean-burning, easy-to-use fuel is projected to grow rapidly. Transportation costs for gas imports from countries other than Canada and Mexico, which have pipelines in place, are extremely expensive. FETC efforts to increase our natural gas supply include technologies to recover more of our conventional supplies, and to develop non-conventional supplies from tight sands, coal beds, and natural gas hydrate deposits.



FETC is also developing technologies that require less fuel to provide the required energy. U.S. power plants operate with an average efficiency of about 33 percent. FETC is developing technologies for power generation from gas, coal, and blends of fossil and renewable fuels that can be installed on existing or new power plants to raise efficiencies and reduce emissions. In the mid timeframe, new technologies will be available with efficiencies greater than 50 percent; longer-term solutions will provide efficiencies exceeding 70 percent. Deployed in a 21st century plant, these technologies could eventually result in needing only half the fuel that is used in a currently operating plant. FETC is also developing advanced fuels for use in more efficient engines, which will result in doubled automobile fuel efficiency without reduced space or comfort.

Environmental Challenges

Americans desire a clean environment and have expectations that the environment will continue to become cleaner. FETC is developing technologies to reduce emissions of pollutants from power generation facilities to vanishing levels and at modest costs. In addition, there is considerable scientific concern about potential global climate change that may be attributable to increased utilization of fossil fuels. The U.S. is a signatory of the recent Kyoto treaty concerning these matters. (See page 13.) Quantitative scientific answers on the magnitude of potential climate changes and their effects on people and ecosystems will require additional research. Nevertheless, FETC activities to develop high-efficiency power systems and recover coalbed methane would reduce the potential magnitude of climate changes. FETC is also conducting long-range research on sequestration of carbon dioxide—in case sequestration is eventually required to ameliorate climate-change effects.

Vision 21 and CO_2 Sequestration

DOE's drive to improve energy efficiency and address local and regional needs for heat, steam, fuels, chemicals, or carbon products has centered FETC's research and development (R&D) on the Vision 21 effort. For the next century, FETC envisions an integrated complex of sophisticated technologies that combines power generation, manufacturing, and the option of CO_2 sequestration into a highly efficient ***Vision 21 EnergyPlex***. An EnergyPlex is a modular, adaptable, high efficiency, nonpolluting energy facility that can be integrated into a specific market, community, or region.

There is no single magic bullet to provide the clean energy required for economic prosperity in the 21st century. Clearly, a multifaceted approach is needed and FETC is responding to the challenge by offering energy solutions. Some of these energy solutions are discussed in greater detail in this issue of *FETC Focus*.

1. ***Vision 21:*** This "crown jewel" of FETC's programs integrates energy and environmental technologies. Vision 21 combines advanced energy and pollution-control technologies into customizable packages that offer higher net efficiency than stand-alone technologies.

2. ***Develop more efficient electric power generation with lower emissions:*** FETC is developing systems that burn less coal and gas to obtain energy, while reducing emissions.

3. ***Increase natural gas supplies:*** FETC develops economically and environmentally sound technologies for natural gas detection, extraction, conversion, distribution, and storage.

4. ***Engage the international community's interest:*** FETC is actively promoting the use of improved technologies internationally.

5. Promote energy conservation: FETC's Energy Management Services are available to help government facilities meet mandatory energy-reduction targets.

A fleet of Vision 21 EnergyPlexes will be capable of providing low-cost energy from coal (at better than 60-percent efficiency) or natural gas (at better than 75-percent efficiency) while coproducing fuels and chemicals and achieving reduced CO_2 emissions. Vision 21 is a culmination of existing R&D on fossil-fuel power generation that will take advantage of the full potential of our abundant fossil-fuel resources.

The Vision 21 EnergyPlex attacks the energy problem from all sides at once: energy supply, power-generation efficiency, and options for CO_2 sequestration. The EnergyPlex integrates many technology components, including coal gasifiers, hot gas cleanup systems, fluidized-bed combustion, fuel cells, advanced turbines, high-temperature heat exchangers, oxygen and hydrogen separators, and conversion processes. The goal is a "green" facility whose only significant environmental impact is its physical footprint on the ground, and even the size of the footprint is being reduced.

Sequestration refers to the capture and storage of CO_2 emissions to prevent them from entering the atmosphere. This long-range technology is being developed in parallel with Vision 21 in case the U.S. decides to sharply curtail its CO_2 emissions in the future. Sequestration could also be applied to existing facilities. Storage possibilities include natural sinks, such as the ocean, and various underground reservoirs, such as unminable coal beds, deep saline (salt water) aquifers, and depleted oil and gas reservoirs. Sequestration in these environments is expected to be effective for centuries.

CO_2 Sequestration

CO_2 Enhanced Natural Sinks

- Ocean (Dissolves CO_2)
- Green Plants (Forest, Cover Crops, Algae, Phytoplankton)

CO_2 Capture

CO_2 Direct Sequestration

Geologic Storage

- Unminable Coal Beds
- Old Oil & Gas Fields
- Aquifers

Research on actual processes that sequester CO_2 is just beginning. Initial research is focused on deep sea and underground injection and injection into unmineable coal beds. Deep sea injection is inviting because the ocean is the largest natural reservoir of CO_2, containing more than 50 times the carbon in the atmosphere and more than 10 times the carbon in all recoverable fossil fuel reserves. Deep subterranean injection would pump CO_2 into deep underground rock formations. Injection into unmineable coal beds is desirable because the coal contains natural gas that would be displaced by the CO_2 and could be recovered as additional fuel. The value of the natural gas would help offset the cost of sequestration.

Greenhouse gas reduction would require development and demonstration of a whole new portfolio of viable CO_2 sequestration technologies. As an early step, FETC is developing an engineering database to help determine how much of the CO_2 that is generated at a particular location could be sequestered, where it could be sequestered, at what distance, and at what cost.

CO_2 sequestration is intimately related to other fossil energy research. It is an integral part of Vision 21.

More Efficient Electric-Power Generation

The energy sector is responsible for close to 80 percent of humankind's CO_2 emissions. Nearly 60 percent of all electricity generated worldwide comes from power plants that burn fossil fuels, either coal or natural gas. The current fleet-average efficiency for all fossil-based electricity generators in the U.S. is only about 33 percent. Improving efficiency will pay benefits in all respects, including lower costs, lower emissions of pollutants, less need to use limited fossil resources, and reduction of CO_2 emissions because less fuel is burned.

FETC already has developed and demonstrated advanced turbine systems. The promising strategy of cofiring biomass with coal uses technologies that have been demonstrated by FETC. Both utilize our natural resources more effectively and also reduce net CO_2 emissions.

Advanced Natural Gas Turbine Systems—Much of the near-term growth in power generation will be through installation of gas turbines. Today's gas-turbine efficiency is around 30 percent, but in a combined cycle system, it can exceed 50 percent. FETC is developing technologies to boost combined cycle efficiency to 60 percent or greater, thereby reducing CO_2 emissions by nearly 20 percent. DOE-supported advanced-turbine-system technology is already being incorporated in current manufacturing.

Biomass cofiring—Burning of biomass (wood, sawdust, etc.) is environmentally friendly, because it can effectively utilize waste products such as bagasse, tree bark, and waste wood, thus preventing the pollution relating to disposal of these products and avoiding the environmental impacts of fossil-fuel extraction. The CO_2 originally consumed from the atmosphere by plants during photosynthesis is returned to the atmosphere later when the plants are burned. Since burning of biomass adds no extra

CO_2 to the atmosphere, displacing some coal with biomass during cofiring reduces the net addition of CO_2 to the atmosphere, compared to firing coal alone. Cofiring results in more efficient utilization of the biomass than biomass-only power facilities and helps facilitate the eventual transition to a sustainable energy supply. Cofiring is already in use or under test at several utilities, and FETC is working to enhance the near-term potential of cofiring.

Natural Gas Supply

Natural gas is useful in high-efficiency combined-cycle power generation that integrates combustion turbines and steam. At the current price for natural gas (which is expected to remain stable), gas provides the least-cost option for new electric power plants wherever natural gas is available. Natural gas contains almost no sulfur and nitrogen oxide emissions from its combustion are low, resulting in little environmental degradation from natural-gas power plants. In addition, the resulting CO_2 emissions from natural-gas power generation is about half that from coal, making gas an extremely attractive fuel.

To meet the growing demand, FETC is implementing a DOE program to increase reserves and production of gas. The program has two components: one near term, one visionary. Near-term, the goal is to enable an increase in domestic gas consumption by 27 percent, from 22 trillion cubic feet (Tcf) in 1995 to 28 Tcf by 2010. Strategies to achieve this are (1) developing conventional natural gas reserves more efficiently, (2) improving gas extraction from “tight” geologic formations, and (3) recovering methane from coal beds.

The visionary part of the program has FETC scientists investigating what is perhaps our planet’s greatest natural gas resource: methane hydrates, which are ice-like solids made of natural gas (methane) and water. They occur beneath the Arctic permafrost and beneath the ocean floor. The size of the resource is imprecisely known, but vast areas of hydrates have been identified in the Gulf of Mexico, Alaska, Canada, Russia, and off the coasts of several states.

FETC has led government research in methane hydrates since interest first developed in 1982, and with the renewed interest in this resource, FETC once again is studying ways to produce commercial gas from this unconventional resource.

International Cooperation and Conservation

Two other strategies are extremely important in reducing the environmental impacts of greater usage of fossil fuels on a worldwide basis: (1) getting other nations of the world on the same page with us in deploying superior technologies, and (2) attacking the demand-side of the energy equation by promoting energy conservation.

International Cooperation—Simply put, international cooperation involves persuading people to adopt our advanced technologies, so they won’t undergo the same long, inefficient, pollution-generating development that we have. Reducing CO_2 emissions and

other pollutants are important goals of this cooperation, but there are also huge economic stakes. The energy market is now global, and how effectively we interact internationally will affect our own prosperity. We must maximize the effectiveness of federal R&D dollars through promotion and deployment of clean, efficient energy systems worldwide and through cooperative research and technology development with other nations.

Energy Conservation—Equally important is the demand side of the energy equation. Our other strategies for limiting pollution from utilization of fossil energy and making efficient use of our limited natural resources involve the supply side. The trick, of course, is improved efficiency—more efficient lighting, heating, cooling, transportation, communication, computing equipment, etc.—consuming less energy while enabling economic expansion.

The Energy Policy Act of 1992 mandates reduced energy consumption in all U.S. government buildings (over 3 billion square feet of floor space), and the Federal Energy Management Program administers the national effort. FETC's Energy Management Services Group provides scientific consultations on energy efficiency to other government agencies.

The outcome of FETC's aggressive technology development and deployment will leave future generations of Americans a more livable nation that enjoys a thriving energy sector and a variety of safe energy alternatives. Many of the technology programs just discussed are presented in the following articles in this issue of *FETC Focus*.

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"Prudence clearly dictates that new technologies be developed to provide additional options to meet evolving environmental, economic, and security needs."

Comprehensive National Energy Strategy, April 1998, page 9.

"Ultimately, the continued development of new technologies that provide diverse energy resources, improve the efficiency of end-use, and reduce the negative environmental effects of energy production and use is key to maintaining our high quality of life. . . the Government ensures the flow of new and cleaner energy technologies by funding energy research, development, and demonstration."

Comprehensive National Energy Strategy, April 1998, page 2.

Lawrence A. Ruth

Product Manager, Pulverized Coal Combustion

Office of Power Systems Product Management

Vision 21

The "Ultimate" Energy Complex

"Can you develop the ultimate energy facility—not simply the next generation facility, but the ultimate facility? And not just the ultimate power facility, but the ultimate energy facility—where every usable Btu in coal or biomass, or perhaps a fuel mix, is extracted and used for electricity and process heat, fuels, chemicals or combinations?"

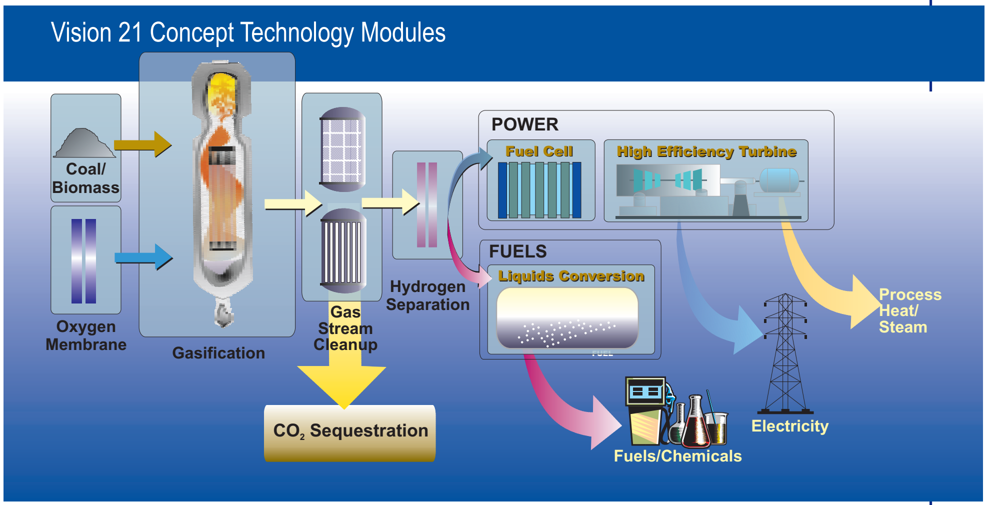
That was the challenge issued to the coal research and development (R&D) community by George Rudins, Deputy Assistant Secretary, Coal and Power Systems, in the U.S. Department of Energy (DOE) Office of Fossil Energy. The result: Vision 21.

DOE has devised an R&D roadmap known as Vision 21, a technology laden avenue seeking to provide the United States with a host of energy products—not electricity alone—by 2015. More specifically, Vision 21 refers to a fleet of advanced, ultra-clean, highly efficient power plants capable of producing several energy products: electricity and steam, as well as premium chemicals and feedstocks, and clean liquid fuels. Virtually every energy-using sector—residential, commercial, industrial, transportation—would benefit. These plants, appropriately enough, are called EnergyPlexes.

FETC Technologies Figure in Vision 21

Several technologies now in the R&D pipeline at the DOE's Federal Energy Technology Center (FETC) are to be incorporated in

Artist's conception of a Vision 21 EnergyPlex, the crown jewel of FETC's fossil energy research and development.



Vision 21 EnergyPlexes. Advanced turbines, fuel cells, indirectly fired cycles, and integrated gasification combined-cycle (IGCC) systems, all FETC-managed products, form the nucleus of Vision 21, a culmination of today's cutting-edge technologies created through partnerships between FETC and private companies. Each system emphasizes high efficiency, low emissions, and little CO_2 output—a Vision 21 maxim.

"Vision 21 is not so much a 'new start' as it is a new way of thinking about our existing technologies..." summarizes Mr. Rudins, "and working to tie them together in the most flexible, efficient way in the future."

Because plant efficiencies in a Vision 21 configuration would reach and eventually exceed 60 percent when coal is the feedstock and 75 percent when using natural gas, less fuel would be required. A flexible design ensures that some Vision 21 units could be equipped with a CO_2-capture device, an option that would make them virtual "zero discharge" plants. A 60-percent efficiency rating represents marked improvement over today's most efficient coal plants, which strive to reach 40 percent, and extremely efficient natural gas units, which can top out at 58 percent. Combining high efficiency with CO_2 sequestration, Vision 21 plants would effectively address climate change concerns while ensuring that fossil fuels, especially coal, remain an important part of our energy supply.

In addition, Vision 21 plants, projected to be built across the nation, would be able to operate on several fuels: coal, natural gas, and, in time, combinations of fossil fuels with biomass or municipal solid waste. Such a feature would help ensure that our land and waterways, along with air, remain clean.

Technology Goals

The primary goal of Vision 21 is to develop a set of advanced technology modules that can be integrated and configured to create the EnergyPlexes, which, in turn, are tailored to specific energy markets of the future. These interchangeable modules are to provide Vision 21 plants with flexibility.

In a Vision 21 setting, advanced turbines, gasifiers, high-temperature combustion systems, or fuel cells would be used in modular form to generate power. Early versions of these technologies are beginning to enter the commercial market. DOE-funded research will accelerate advancements. Ultimately, these systems could be fine-tuned for Vision 21 applications.

Because EnergyPlexes could be customized, they could better respond to specific needs of local markets. For example, an EnergyPlex may be equipped to produce electricity along with low cost fuels and chemicals near areas with several chemical-processing companies. Another EnergyPlex may be tailored to coproduce low priced feedstocks in regions where there is a market demand for them.

How a Vision 21 EnergyPlex Could Operate

- A gasifier burns fuel and sends the gas to one or more modules that use the gas for specific purposes.
- One module would rid the gas of pollutants and particulate matter and then would channel it to a fuel cell module, which generates electricity.
- Fuel cell exhaust would be used to drive a turbine that produces power.
- A portion of the cleaned gas could be siphoned off and funneled to a synthesis gas module that yields fuels and chemicals.
- Another module also could be added to capture CO_2 and pump it into the ground or store it for other uses.

Business Strategies

While feedstock coproduction won't be available for several years, we won't have to wait long for other Vision 21 benefits. Some may be realized as early as next year with the advancement and progress of several DOE-sponsored technologies, including those stemming from the Clean Coal Technology (CCT) Program, that are to play a role in Vision 21 EnergyPlexes. Indeed, several CCT projects like IGCC systems are now demonstrating that clean, affordable electricity can be generated from coal plants.

As technologies such as fuels cells, which use an electrochemical process to generate electricity somewhat like a battery, and IGCC become commercialized, they will contribute environmental benefits—fossil fueled power production with low emissions. Such contributions can be realized even before Vision 21 is commercialized in the post-2110 timeframe.

Just as the CCT Program is a government-industry cost-shared program, Vision 21 is seen as a cost-shared, industry-driven program that will most likely require the efforts of teams composed of private companies working together. Government involvement is necessary not only to coordinate the work of participants, but also to help share the risks of technology development.

The energy industry is beginning to restructure itself. It is expected that the price of electricity will drop when competition begins in retail markets. Competition and restructuring, according to DOE's Fossil Energy Strategic Plan, will prompt industry to reduce longer term research, development, and demonstration (RD&D) investments "for... advanced, low-emission fossil fuel technologies," and focus on near term operational issues, reinforcing the need for federal government participation.

Vision 21 stakeholders will represent a broad cross section of organizations vitally concerned about energy options, including industry, state governments, universities, laboratories, and other interest groups.

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DOE Seeks Participants Who Will:

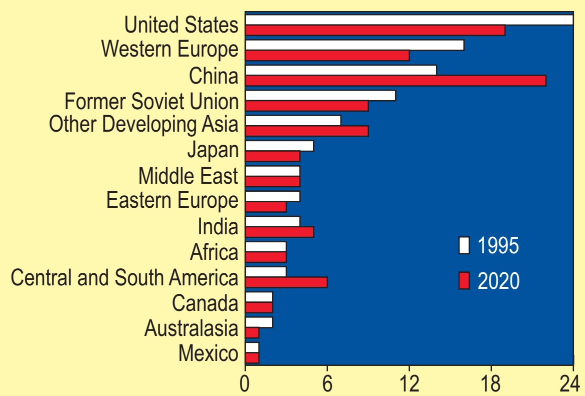
- Expand existing partnerships and linkages with industry, private and public R&D laboratories, and with other state and federal programs.
- Create technology options that are both technically and economically feasible, and identify approaches and products that have substantial market and profit potential.
- Identify and overcome barriers prohibiting the commercialization of Vision 21 plants, by helping develop enabling technologies or by exploiting new information and existing approaches.
- Develop a structured RD&D roadmap approach and schedule complete with decision points for meeting Vision 21 goals.
- Identify and prioritize needed resources to conduct the RD&D program.

Coming to Agreement . . .

This excerpt summarizes a U.S. State Department fact sheet on the Kyoto Protocol, *which was developed by the U.S. and more than 150 other nations at a conference in Kyoto, Japan, in December 1997. This protocol is designed to reduce greenhouse gas (GHG) emissions worldwide. We offer this summary as a service to our readers.*

- *The historic Kyoto Protocol will reduce GHG emissions by harnessing the global marketplace to protect the environment.* The Protocol reflects several U.S. proposals for emissions targets and timetables for industrialized nations, and market-based measures for meeting those targets. The Protocol also makes a down payment on meaningful participation by developing countries.
- *The Protocol includes binding emissions targets for developed nations.* Limits vary—8 percent below 1990 emission levels for the European Union, 7 percent for the U.S., and 6 percent for Japan. For the U.S., the 7-percent target represents at most a 3-percent real reduction below President Clinton's initial proposal to reduce GHG to 1990 levels by 2008 to 2012. The remaining 4 percent results from changes in the way GHG gases and sinks are calculated. Altering the accounting method for carbon-absorbing activities, such as tree plantings, accounts for about 3 of the 7 percent reduction.
- *Emissions targets for all six greenhouse gases are to be reached over a 5-year U.S.-proposed budget period.* This increases flexibility by smoothing short-term fluctuations in weather and national economies. The first budget period is 2008 to 2012, allowing time to improve energy efficiency and technology.
- *Activities that absorb carbon, such as tree plantings, will be offset against emissions targets.* The role of forests is critical to a comprehensive, environmentally responsible approach to climate change. It also provides the private sector with low-cost opportunities to reduce emissions.
- *The Protocol includes emissions trading.* This free-market approach, pioneered in the U.S., allows countries to seek the cheapest emissions reductions. Countries or companies can purchase less-expensive emissions permits from countries that have more permits than they need (because they have met their targets with room to spare). Emissions trading can be a powerful economic incentive to cut emissions while allowing flexibility.

Regional Shares of World Carbon Emissions, 1995 and 2020



Sources: 1995: Energy Information Administration (EIA), Office of Energy Markets and End Use, International Energy Annual 1996, DOE/EIA-0219(96) (Washington, DC, February 1998). 2020: EIA, World Energy Projection System (1998).

Abbie W. Layne

Product Manager, Advanced Turbine Systems

Office of Power Systems Product Management

ATS More Efficient, Cleaner Power Generation

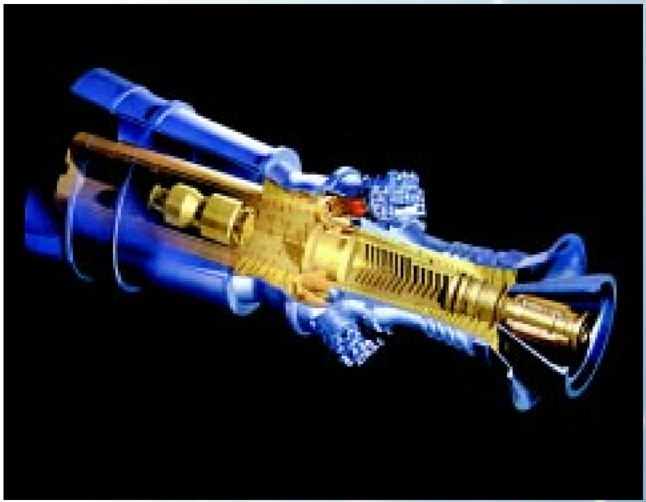
In addition to boosting efficiency, which means less fuel is used and therefore fewer pollutants are released into the air, other improvements developed through the Advanced Turbine Systems (ATS) Program are so successful that turbine manufacturers have already incorporated them into current models.

The Federal Energy Technology Center (FETC) is addressing the challenge of utility deregulation by developing advanced turbines. In a combined cycle system, these machines will be 10 percent more efficient and will produce less than half of the nitrogen oxides of currently commercial gas turbine systems. Equally important to the utility and the consumer, as long as natural gas prices remain at current levels, these systems will produce electricity at lower cost than any other new generating source.

“DOE-supported ATS technology has already yielded benefits for current combustion turbines,” notes Abbie Layne, FETC’s ATS product manager. Specific turbine designs aside, the program has led manufacturers to upgrade existing equipment through better blade development, coatings, and similar improvements.

A case in point is the transfer of ATS technology to General Electric’s gas turbines and their suppliers. Airfoil casting development, which deals with creating turbine blades, has improved with the use of manufactured, thin walled, complex, single crystal castings for future advanced gas turbines. Single crystals, much stronger than the multi-directional crystal design now used in manufacturing blades, are better able to resist high temperatures, cracking, and other problems associated with turbine use. And the methodology employed by GE and a major casting supplier has improved the way blades are produced and the number of blades that are produced. As a result, future thin-walled airfoil development programs are expected to achieve quality and cost targets at a faster rate. In addition, selected process improvements, like new core support methods, are already part of a

The General Electric Corporation’s G gas turbine product line features improved blade design and enhanced thermal barrier coatings.



program to enhance GE's F gas turbine product line. Also planned for near term F-product enhancements are thermal barrier coatings.

Areas being explored in the ATS Program include telemetry technology, which uses radio-like signals to measure a blade's rotations and vibrations. This technology adds new capabilities for obtaining real-time data to characterize gas-turbine operating behavior, and is being considered for three significant new product development programs. Pyrometer technology, measuring a blade's temperature and other factors, is being evaluated as a way of helping evaluate the condition of gas turbines in GE's fleet. This enhanced monitoring capability is expected to add value to maintenance and life-extension activities.

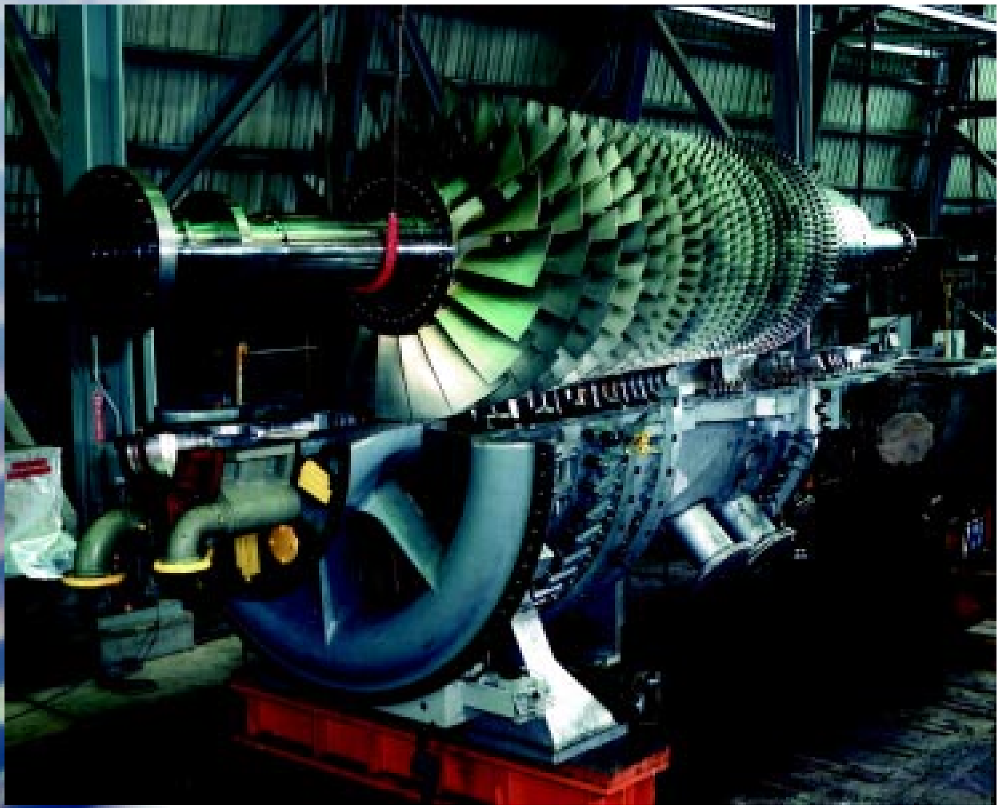
Capturing a Growing Global Market

The object of such improvements is a very sizable market. Right now, gas turbines are a $3.5 billion industry in the United States. Globally, the market promises to be huge. From 1997 to 2006, Forecast International, a private marketing and consulting firm, expects the gas turbine industry will reach $251 billion with worldwide power generation accounting for $86 billion. Industrial and marine uses are expected to represent $96.5 billion during the same time period.

Advanced turbines are poised to dominate the majority of this power market, primarily because the ATS design is being incorporated into today's turbines and existing technologies to boost efficiency. Current ATS strides put overall efficiency at slightly more than 60 percent for utility-scale systems, a significant jump over the 42-percent efficiencies that the best coal plants now achieve. Another dimension that enhances ATS's attraction is its fuel flexibility. ATS will have the capability to operate on a coal-derived synthesis gas as well as natural gas, the most commonly used fuel today.

There is no doubt that gas turbines fueled by natural gas or a coal-derived synthesis gas will take on a significant role in providing heat and energy for power generation, cogeneration, and steam turbine combined cycles in the foreseeable future. In fact, the Energy Information Administration estimates that gas turbines will satisfy as much as 81 percent of new electric power demands in the United States alone. A study sponsored by Westinghouse Electric Corporation

Installation of the Westinghouse Electric Corporation compressor rotor into the compressor casing. The compressor is the largest, highest pressure ratio, 60 Hz utility combustion turbine compressor ever built.



projects the total world demand for electricity will exceed 1,690 gigawatts (GW) between the year 2000 and 2014. The utility-scale potential market is quite large, more than 300 GW. It is a demand that will be met by simple- and combined-cycle ATS. The market for small industrial-scale ATS is expected to be about 127 GW.

Slicing Up the Market

Natural gas, the entry-level fuel for ATS generation, is projected to supply 473 GW of this market. Advanced solid-fuel power systems now being developed are expected to incorporate ATS turbines, resulting in a larger market for these machines. Utility ATS penetration into the market for integrated gasification combined-cycle (IGCC), pressurized fluidized-bed combustion (PFBC), and indirect-fired cycle (IFC) systems is expected to begin in 2005, as solid-fuel-based power-system commercialization accelerates. IGCC systems could capture 40 GW of the world's power-generation market by 2006, says Forecast International.

Program participants are also studying the benefits of integrating ATS designs into coal-fired cycles, such as IGCC. The IGCC plants now in operation are funded through the Clean Coal Technology (CCT) Program because they can use a coal-based gas. In addition to data from these CCT projects, laboratory combustion studies being conducted at FETC are evaluating fuel flexibility for industrial-scale systems as well as utility use.

The huge potential market will drive future gas turbine technology to produce energy in a reliable, cleaner, more efficient, and less costly manner than ever before.

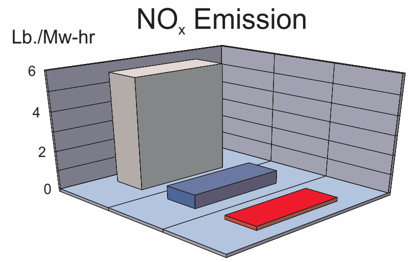
Market Drivers, Global Competition

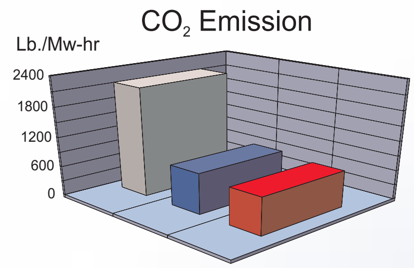
While these factors are the drivers behind the introduction of ATS technology, the primary emphasis is on emissions. The growing need to lower emissions, especially NO_X and CO_2, and a demand for high efficiencies to keep natural gas consumption and costs low are the most important reasons behind ATS evolution. New ATS designs evolving through the program, projects Ms. Layne, will reduce NO_X to less than 9 parts per million (ppm).

High efficiencies, of course, also reduce production of CO_2, which a report from the Intergovernmental Panel on Climate Change suggests is having a discernible influence on global climate. CO_2 has increased by 25 percent over the past century. That is a fact that most experts agree on. What is less certain is where we go from here.

U.S. manufacturers have dominated the worldwide gas turbine market since its inception. But recently, foreign systems have capitalized on breakthroughs and improvements that advance the technology. A major leap is required for American manufacturers to regain their edge in this vital technology that is sure to capture the bulk of the burgeoning electric-generation market.

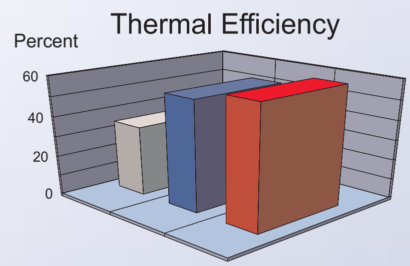
A New Standard In Environmental Stewardship

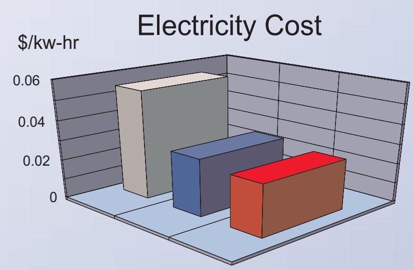




- *Less NO_x in one year than existing plants produce in under two weeks*
- *Less CO_2 in one year than existing plants produce in under four months*
- *No acid rain producing SO_2*
- *Billions of dollars saved on environmental compliance—better economic competitiveness*

60% Efficiency Breakthrough





- *$7.0B in consumer electricity savings by 2015*
- *Enough gas savings to heat over 17 million homes by 2015*
- *ATS fuel savings over 300,000 barrels of oil per day by 2015*
- *Over 70% efficiency improvement vs conventional steam*

Existing coal power plant
Current combined-cycle gas turbine
Advanced combined-cycle gas turbine

The DOE ATS Program

These developments emphasize the vital need for the federal government to participate in technology development. DOE recognized this need in 1992 when it initiated the ATS Program. This program combines the resources of the government, major turbine manufacturers, and universities to advance gas turbine technology and to develop systems for the 21st century.

DOE and individual participants fund ATS projects in such a way that the level of cost-sharing from the participants increases as the technology risk decreases. During the final phases of the ATS Program, participants will provide more than half of the financial support needed to sustain the Program.

Two ATS Classes

- The simple-cycle industrial gas turbine is being developed for distributed generation and industrial and cogeneration markets.
- The combined-cycle gas turbine is being developed for use in large, baseload, central station, electric power generation markets.

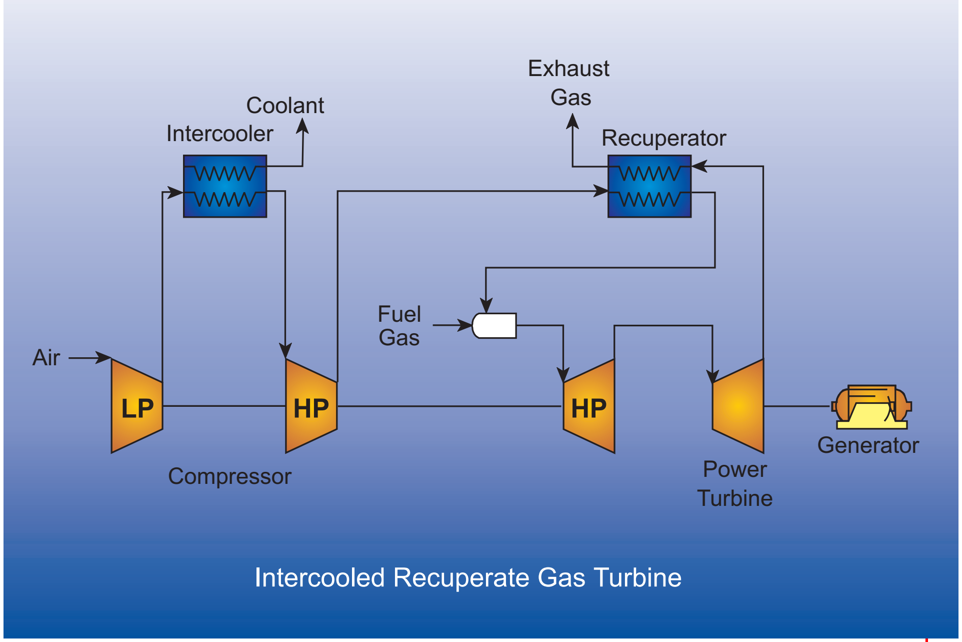
ATS development consists of two major, interrelated thrusts:

1. Major Systems Development is carried out by turbine manufacturers actively engaged in developing an ATS. Four corporations are working on detailed engine designs and hardware through the technology readiness and validation testing phase within the program.

2. Technology-Base Research supports the development of major systems, but the primary concern is evaluating future advancements for gas turbine systems. Academic research and applied research not slated to be used in future ATS demonstrations is pursued in technology-base activities.

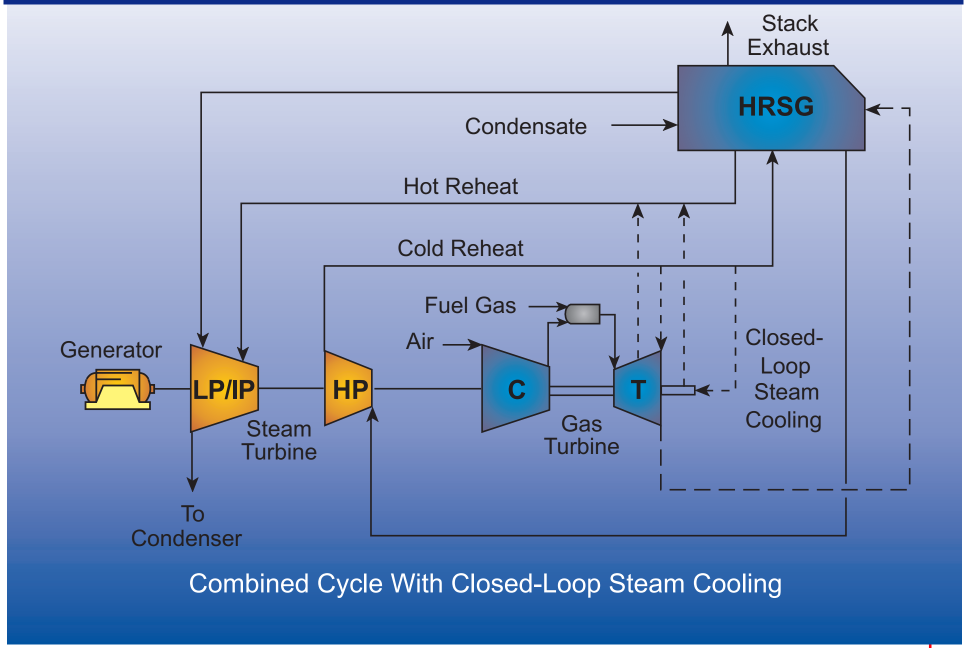
The Office of Fossil Energy supports the utility-scale system development, industry/university consortium, materials research for single crystal turbine components, FETC technology-base research and development, and ATS applications for coal-derived fuels.

Industrial Advanced Gas Turbine System



Intercooled Recuperate Gas Turbine

Utility Advanced Gas Turbine System



Combined Cycle With Closed-Loop Steam Cooling

The Office of Energy Efficiency and Renewable Energy supports the industrial-scale system development, materials research on thermal barrier coatings, ceramic retrofit engine development, and ATS applications for biomass fuels.

Today four major turbine manufacturers are participating in Phase III of the ATS Program, the technology readiness and validation testing stage. Allison Engine Company and Solar Turbines are developing industrial-scale ATS technology. Westinghouse and General Electric are pursuing advancements in utility-scale applications.

Each organization has completed a conceptual design of an ATS, which differs in specifics, but shares many overall features to attain desired efficiencies and restrict emissions.

In general, turbine inlet temperatures are increased; lean, premixed or catalytically enhanced combustors are being developed; less cooling air is being used through improved cooling schemes, upgraded materials, or improved seals; aerodynamic designs are being improved; and better thermal barrier coatings are being developed.

ATS development is bolstered by a consortium of more than 93 universities in 33 states. Coordinated by the South Carolina Energy Research and Development Center, an administrative branch of Clemson University, technological advances are being pursued while fundamental, base knowledge of turbines grows. Central to this knowledge is better understanding of the science of high-temperature, corrosion-resistant materials, combustion, innovative thermodynamic cycles, and how pollutants are formed when fuels are burned and how they can be prevented from forming.

To date, the consortium has selected 51 projects that include: (1) combustion to improve fuel utilization and minimize environmental effects, (2) heat transfer and aerodynamics to upgrade turbine blade life and performance, and (3) materials to extend life and allow higher operating temperatures for more efficient systems.

FETC Contributions

Under the Technology Base Program, FETC scientists have developed a cost-effective and time-saving test combustor for manufacturers to use. This device ensures that a proper match is made between low-emissions combustors and turbines, thereby avoiding turbine damage caused by uncontrolled pressure oscillations. A turbine manufacturer is now using the test combustor, which incorporates cost-saving advantages in its design.

ATS Program Goals

- Efficiencies greater than 60 percent for natural gas, large-scale, utility turbines, and a 15-percent improvement for smaller industrial-scale turbine systems.
- NO_x emissions less than 9 ppm and carbon monoxide and unburned hydrocarbon emissions less than 20 ppm—without post-combustion cleanup.
- Fuel-flexible systems initially designed for natural gas and adaptable for coal-based syngas and biomass fuels.
- Busbar energy costs at 10 percent less than vintage 1992 turbine systems meeting similar environmental standards.
- Reliability, availability, and maintainability equivalent to or better than current state-of-the-art systems.

FETC is working with the United Technologies Research Center (UTRC) to identify and address key R&D issues for humidified combustion turbine cycles. The purpose of this Humid Air Turbine (HAT) research is to identify a combustor configuration that will efficiently burn high-moisture, high-pressure gaseous fuels with low emissions. Using UTRC's experience with aero-derivative engines as a basis, researchers are comparing test data to computer models. Currently, shakedown testing of combustor nozzle designs is occurring; the intent is to provide scale-up data for subsequent hardware development. The HAT cycle development work supports both gas- and coal-fired advanced cycle systems.

Vision 21

Advanced turbines also figure prominently in the DOE's Office of Fossil Energy Vision 21, a fleet of super-efficient, flexible energy plants for the 21st century. These plants would produce clean, high-efficiency power while simultaneously producing clean fuels, chemicals, or heat as local needs require. Advanced turbines will most certainly be needed to achieve these realistic and much needed goals for the next century.

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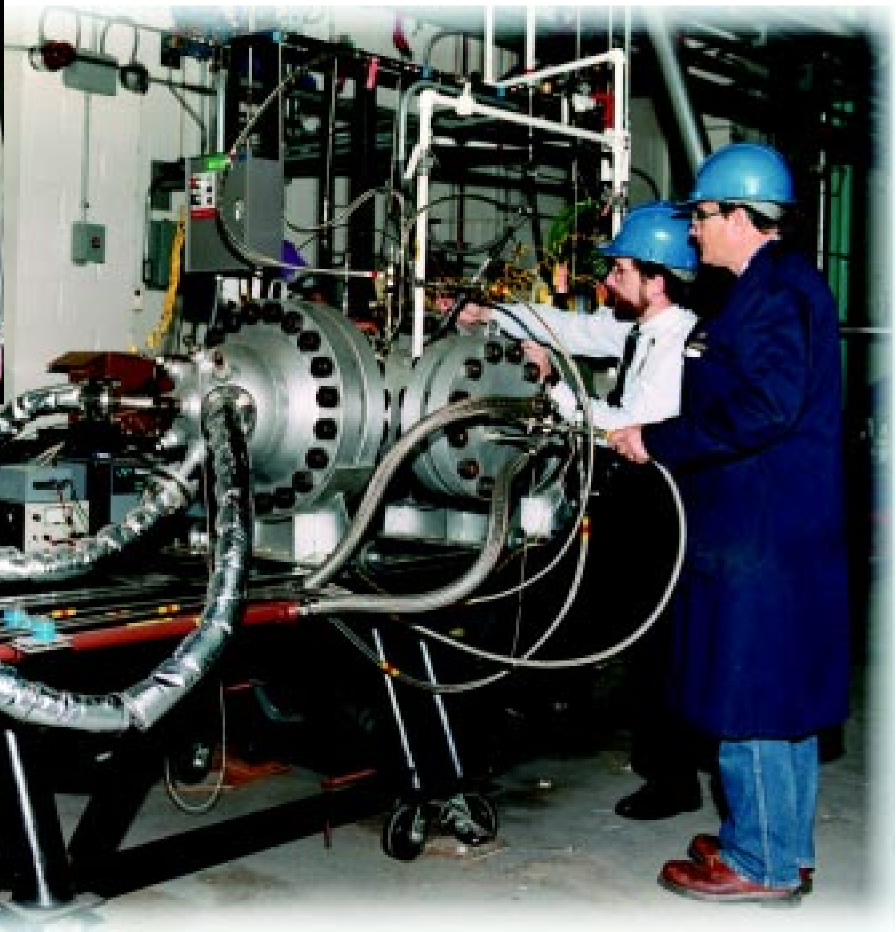
FETC scientists and engineers, in partnership with university researchers and industrial developers, collaborate to move advanced gas turbine technologies into the marketplace to meet the power needs of the 21st century.



Charles W. Byrer
Project Manager/Geologist, Fuels Resources Division
Office of Project Management

Coalbed Methane Gas

From “Miner’s Curse” to Valuable Resource

The coal industry used to look disdainfully at the natural gas that permeates most coal beds, regarding it only as a dangerous waste product. Indeed, coalbed gas was nicknamed the “miner’s curse,” because it escapes from coal seams and can ignite explosively.

The miner’s curse is now an energy opportunity—and an environmental problem.

Gas explosions have killed thousands of miners over the years. The worst U.S. mine disaster of the twentieth century occurred in the Federal Energy Technology Center’s (FETC’s) own back yard—361 miners perished in a gas explosion at Monongah, West Virginia, in 1907.

We’ve come a long way since then. Natural gas in coal mines will always be a hazard, but the risk of explosion has been greatly mitigated by safety regulations, sensitive gas detectors, and mine ventilation with powerful fans that exhaust the gas into the atmosphere.

And therein lies both an opportunity and a possible risk of global climate change. Although venting

gas into the atmosphere has reduced underground explosions to infrequent events, it also discards potentially valuable fuel and adds methane—the chief component of natural gas, and a potent greenhouse gas—to the atmosphere. Thus, the large volumes vented by mines represent both an economic loss and an environmental challenge.

In 1990, up to 300 billion cubic feet of methane were vented from U.S. coal mines (mostly underground operations). This is 15 percent of all global methane emissions from coal mining, and nearly 10 percent of all methane released into the atmosphere by humankind.

Furthermore, methane's greenhouse gas potential is many times greater than CO_2's, so its release during coal mining and processing is a concern. Currently, the atmospheric methane concentration is a lesser problem than CO_2, simply because methane is much scarcer in the atmosphere, with only 1/200th the concentration of CO_2. But this is changing: the methane percentage is slowly increasing worldwide, at a faster rate than the CO_2 percentage. The U.S. Geological Survey is forecasting methane to surpass CO_2 as the dominant greenhouse gas in the second half of the 21st century—if its concentration continues to grow at the present rate.

Bountiful Methane in Most Coal Beds

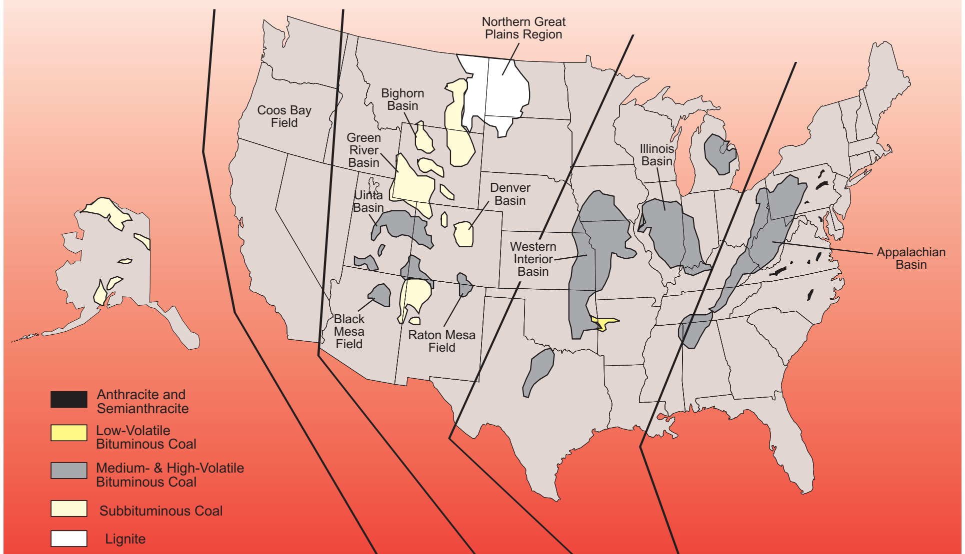
As coal forms slowly from decaying plants over millions of years, methane forms along with it. Thus, most coal beds are permeated with methane, so much so that a cubic foot of coal can contain six or seven times the methane that exists in a cubic foot of a conventional sandstone gas reservoir. However, the methane content in coal is highly variable, varying widely over short distances (a few hundred feet, for example). The higher grades of coal are richer in gas, and deeper coal beds are "gassier" (because they are able to vent less easily to the atmosphere).

The gas often occurs in concentrated pockets as well, creating a major mining hazard. When mining breaks open these pockets, or when coal is pulverized during mining and processing, methane is released into the mine and the atmosphere. In addition to ventilating the operating areas in mines, methane often is removed from the virgin coal in advance of mining by drilling extraction wells into the coal seam and venting the gas into the atmosphere. However, greenhouse gas regulations may limit venting of all types.

Estimates are that 400 to 700 trillion cubic feet (Tcf) of methane exist in U.S. coal beds. Although only 90 to 100 Tcf may be economically recoverable with current technology, this equates to a 4-year supply of natural gas for our nation. More realistically, it can be viewed as a 25-year supply for one sixth of our current annual need. And the world coalbed methane resource spans all populated continents and is estimated at 4,000 to 7,500 Tcf, so it is an extremely large potential energy resource.

The energy (Btu's) in coalbed methane can amount to several percent of the energy in the coal itself. The amount varies widely, from little gas in a ton of coal, up to 5,000 cubic feet. As a general example, burning a ton of bituminous coal can release 21 to 30 million Btu of heat energy, depending on the coal's rank. The methane within that ton of coal—typically 250 to 500 cubic feet of the gas—can provide 250,000 to 500,000 Btu when burned. In many cases, this can make the gas worth recovering as a fuel.

Estimated Coal Resources in the U.S.—90% Considered Unminable



Total Coal to 6000 Feet	2030	100	3260	620	350	Total = 6360
Mineable Reserves	12	2	200	110	110	Total = 430
Unmineable Reserves	640	20	920	140	80	Total = 1800

Coalbed Methane: Already a Commercial Success

Coalbed methane (CBM) has strong economic potential. It can be used to generate electricity, either at mine sites or by pipelining it to commercial utilities. It can be cofired with coal to reduce SO_X and NO_X emissions. It can fuel gas turbines or fuel cells to generate power. At mines, it can fire drying units that remove moisture from washed coal. And it can be pipelined for utility and industrial use. Some of this potential already is being realized.

During the 1930s, the Big Run gas field in northern West Virginia began producing coalbed gas from the thick Pittsburgh coal seam and continues producing to this day, demonstrating a common characteristic of coalbed wells: they tend to produce much longer than conventional reservoirs. By the late 1970s, some CBM was being produced commercially from coal beds in Alabama. In northern New Mexico, 40 billion cubic feet of CBM have been produced from 1,700 wells. Self-supporting CBM projects also exist in Colorado and Virginia. Currently, pipeline-quality coal mine methane is being sold to distribution systems in the Appalachian coal basin.

Today, the annual U.S. demand for natural gas is about 21 Tcf, with more than 1 Tcf being produced from coal mines and unmined coal beds, or nearly 5 percent—quite a success story for what was once a waste product and "miner's curse." And this production is projected to increase as demand rises, as technology improves, and as mining companies cooperate with gas producers to utilize—and maybe turn a profit from—gas that it is desirable to remove from the coal and sequester from the atmosphere.

Coal Mine Methane Pros and Cons

Coal mines can simultaneously produce methane and consume it by generating electricity on site. This on-site capability is valuable because the mining operation needs electrical power to operate machinery and for ventilation fans, coal cleaning plants, coal dryers to remove moisture, and other surface facilities. An underground mine's vent fans alone can consume 75 percent of the total electricity used at the site. Power generated from mine gas also can be fed to the grid that supplies electricity to the mine, selling the energy back to the power supplier. Such uses of mine gas can more than offset its cost of recovery.

FETC has sponsored several field tests to recover coal mine methane and use it to generate power on site. Use of mine gas to fuel combustion engines and gas turbines has been demonstrated. Also promising is the use of mine gas in fuel cells.

One problem with coal mine methane is that its quality varies, particularly if the gas has been mixed with ventilation air in an operating mine. Pipeline-grade natural gas must be at least 97-percent pure methane, so lower-quality mine gas must be upgraded for distribution by removing water and other gases (CO_2, nitrogen, and oxygen).

The gassiest U.S. mines are in the Appalachian coal basin, which stretches from Alabama to Pennsylvania. Some of these mines are recovering and using mine gas. The 1992 methane recovery from U.S. underground coal mines (not including methane tapped from unmined coal seams) was about 25 billion cubic feet.

Commercial successes in this basin include a large Alabama longwall mine that is selling over 40 million cubic feet of pipeline-quality mine gas per day. The largest coal mine methane project in the country is

In northern New Mexico, 40 billion cubic feet of CBM have been produced from 1,700 wells.

in western Virginia, where pipeline-quality mine gas is being sold to a utility.

Recovering methane from operating mines is not all roses. The coal industry has long seen methane as a problem, not a resource, so a different viewpoint is required. Coal beds are far more complex geologically than conventional natural gas reservoirs. Mine gas recovery adds cost in equipment, work force, services, and meeting additional regulatory requirements. Not all mine gas is of pipeline quality. There can be questions of gas ownership and royalty rights. And there is the question of unproven economics of recovery.

But improved technology for recovery, combined with potential utilization and the need to meet future greenhouse gas regulations are nudging CBM toward wider commercial success.

Profit Opportunities in Unminable Coal

Today, coal is mined from thick beds with high-volume mining machinery that feeds a virtual conveyor of road-rail-river transportation to our nation's power plants. This high-volume strategy holds down the cost of coal and electricity, but it also renders about 90 percent of U.S. coal "unminable," meaning that it is unprofitable to mine with present technology. It is unprofitable because of coal-seam thinness, poor or inconsistent quality of the coal, or difficult mining conditions.

But this unminable coal represents a vast, largely untapped *methane* resource. As demand for natural gas increases, coalbed methane is growing more attractive as a fuel. More than 16,000 communities, many in the South, lie above coal seams that could produce methane. This fuel could be delivered locally, reducing the need for interstate gas transportation hundreds of miles from distant gas fields.

CBM is gaining strong interest nationally, but the Southeast U.S. is a particularly promising market, because of its large gas demand and the Appalachian basin's many gassy coal seams. Here we have a large resource near major markets, all lying within an established pipeline infrastructure. CBM is potentially capable of making seven states at least partially self-sufficient in gas supply—Kentucky, Maryland, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia. In West Virginia's case, the state could be 100 percent self-sufficient, satisfying its entire natural gas demand from its own coal beds.

Furthermore, CBM can be locally competitive with conventionally produced pipeline gas. In addition to recovering methane from unminable coal beds, the gas can be harvested from active underground mines as well.

FETC's Pioneering Research in Coalbed Methane

Under the President's Climate Change Action Plan, the Department of Energy is responsible for identifying barriers to developing the resource and methods for its recovery and use. For two decades, FETC has been the lead government laboratory for partnering with the coal, gas, and utility industries to develop and implement the technology for capturing and utilizing coalbed methane, and in sequestering it from the atmosphere.

FETC began extensive CBM research, development, and demonstration in 1977, when government and industry began to look at alternatives to conventional gas sources (mostly sandstone reservoirs). A federal tax credit for CBM production expanded drilling in the mid-1980s, and promoted development of new drilling technology.

FETC and its research partners have come a long way toward developing the CBM resource. FETC has assessed the resource in 16 of the country's 26 major coal basins, and established geologic areas where production is favorable; established guidelines for efficient recovery, and determined that efficiency is greater in horizontal wells; assessed the potential of gas production associated with longwall mining in the Appalachian basin; established valuable partnerships with industry, academia, utilities, and municipalities; and greatly expanded the knowledge base for CBM development.

Convergence at the Millennium: Coalbed Methane and CO_2 Sequestration

International economic, environmental, and technological drivers are converging at the start of the new millennium to make us consider CBM recovery and CO_2 sequestration together. The idea is to sequester CO_2 in unmined coal beds, which have an enormous capacity for CO_2, while at the same time recovering the methane already in them. The CO_2 would be injected via wells drilled into the coal, and pressure from the CO_2 would drive the methane out of the coal through the wells to the surface, where it would be collected. This two-birds-with-one-stone idea is feasible because coal stores CO_2 in twice the volume that it stores methane. The net result would be less CO_2 in the atmosphere, no significant new methane added to the atmosphere, and recovery of methane to help pay for the process.

What about the logistics and cost of this CBM/CO_2 strategy? Most U.S. power plants are within 3 to 5 miles of a coal bed (not necessarily a suitable one, of course). For a plant near a gassy coal bed (or multiple beds, for coal often occurs in multiple seams, like a layer cake), pipeline length would be minimal to convey CO_2 from the plant into the coal, and to pipe recovered methane back to the plant. DOE considers this approach an important option in support of the Climate Change Action Plan and the Kyoto Protocol.

Coalbed Methane's Future

Today, industry and academic research interest is running high because the methane recovery/CO_2 sequestration concept could be a least-cost option in the energy-economy-environment trilemma. But much work lies ahead. Candidate coal beds must be targeted, and the potential methane resource must be determined for each bed. The feasibility of drilling CO_2 injection wells and methane recovery wells must be determined for each targeted bed. All environmental factors must be considered, including surface land use and water quality. Cost is a paramount consideration. And timeframes must be established.

Alberta CBM/CO_2 Project

A consortium of Canadian and U.S. organizations will develop new technology to reduce greenhouse gas emissions. The technology also promises to enhance production from Canada's large CBM reserves. This work, led by the Alberta Research Council and supported by DOE, Environment Canada, and industry partners, is attracting international interest. It is one of several promising environmental projects recognized at the Kyoto conference in 1997.

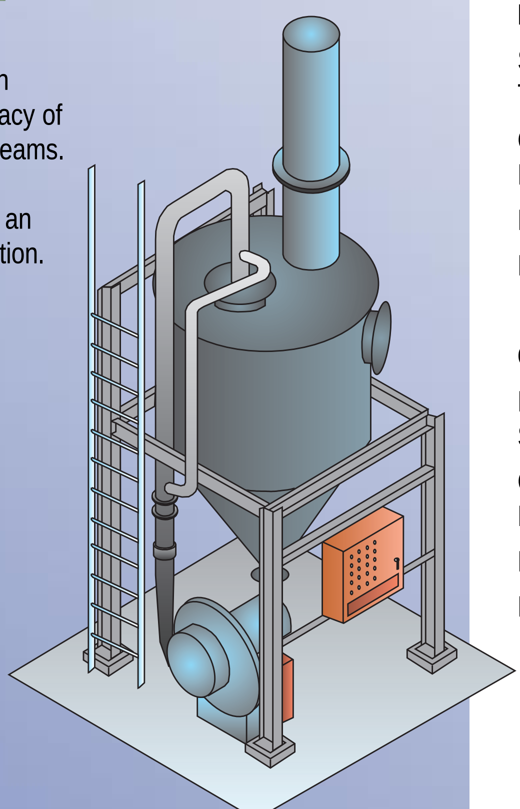
Many of Alberta's coal beds are rich in methane, making this an ideal testing ground to develop new technology. The CBM/CO_2 project is testing CO_2 injection into the province's vast, deep unminable coal beds. This will set the stage for validation of a system to reduce CO_2 emissions while increasing methane production. Results of this field test will be extrapolated to coal beds in the United States and other countries.

Another Success: Brine Management

Attractive though it is, methane from coal beds comes with an environmental price. Coal beds store considerable water in their pores and fractures. Pressure from this water confines the methane within the coal. To free the methane, the coal must be "dewatered" by pumping the water to the surface. Methane wells drilled into coal beds produce exceptionally large volumes of water, averaging more than 13 times the water produced from a conventional gas well. Furthermore, the water is often brine (salty), especially early in production. This creates a major problem of water disposal, for brine is toxic to most plants and freshwater fish. In most cases, the water must be reinjected underground—if permissible at the location. Before our vast resource can be fully developed, environmentally acceptable technologies for brine management need to be adopted.

From this challenge is emerging another success story: a FETC research partner is demonstrating the use of CBM to partially fuel the processing of saline minewater into fresh water for public supply and agriculture, while recovering dried salts from the brine for industrial use. At the Morcinek mine in southern Poland, coal is first dewatered to release the methane. Then a desalting unit (reverse-osmosis) converts up to 60 percent of the brine to fresh water, and methane from the coal is used to fuel an evaporator that further concentrates the brine.

Fresh water is a precious commodity in Eastern Europe, given the region's legacy of severely polluted ground water and streams. Commercialization of this process will provide potable water, and will provide an attractive alternative to deep-well injection.



Direct Fired Brine Evaporator, 50 cubic meters per day

Better technology tomorrow could let us recover methane from coal deposits in regions that are not economic today. For example, the Appalachian coal basin currently accounts for about two-thirds of the coal mine methane emissions in the United States—a rich potential resource.

Properly developing our coalbed methane resource can provide more clean energy, reduce our greenhouse gas contribution, and maintain a safe mining environment. The "miner's curse" that haunts every coal mine is becoming an asset.

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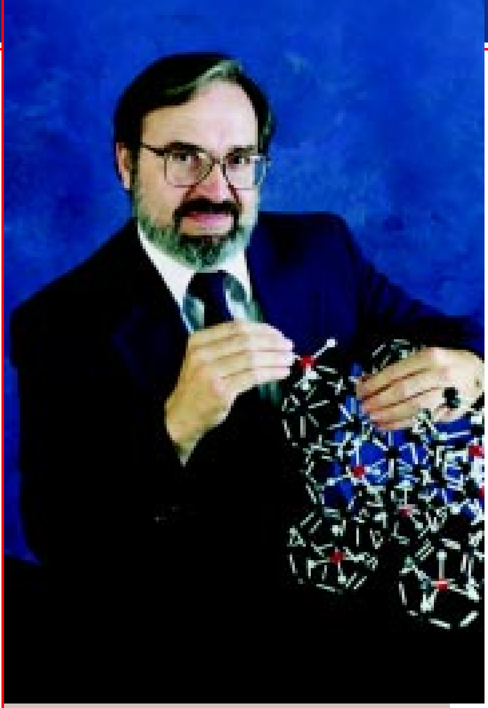

Thomas H. Mroz

Project Manager/Geologist, Fuels Resources Division

Office of Project Management

Hydrates

Fire From Ice

Fire From Ice

If you touch a match to a sample of methane hydrates, the familiar gentle flames of burning natural gas appear, burning steadily as the ice slowly melts into a puddle. This “fire from ice” is by far the largest natural gas resource on Earth.

On a crisp, blue-sky March day in Canada’s Northwest Territories, the low-angle sun cast long shadows from Federal Energy Technology Center (FETC) scientist Thomas H. Mroz and other members of the international drilling team. As armed guards kept a vigil for uncongenial polar bears, the team turned their collars to the -10 °C wind. They waited as the drilling rig penetrated seven-tenths of a mile down through the thick Arctic permafrost. Scientists from a Japanese petroleum company (JAPEX), Woods Hole Oceanographic Institution, the U.S. Geological Survey (USGS), the Canadian Geological Survey, the Idaho National Engineering and Environmental Laboratory (INEEL), and FETC had teamed to sample an extraordinary substance that could provide a vast natural gas supply for the future: ***methane hydrates.***

Methane hydrates are ice-like solids that have methane gas frozen within them. The methane (the main component of natural gas) is

The methane hydrates test well was drilled on Richards Island in Canada’s Northwest Territories. Samples of hydrates were successfully recovered.

locked within a "cage" of ice. Few have actually seen methane hydrates, because they can exist only in cold temperatures and under high pressure. These conditions prevail in places that even scientists do not frequent: beneath the Arctic permafrost and below the seafloor. Bringing a sample of hydrates to the surface rapidly decomposes it, because the reduced pressure and warmer temperature allow the substance to melt, releasing its captive methane.

Far-sighted planners in government and industry know that conventional natural gas supplies are not likely to meet expanding demand, and new resources must be developed during the next two decades. The potential of hydrates has raised hopes of a vast new gas resource to exploit, and it is one of the hottest and coolest topics in energy research today. However, the true extent of the resource is unknown, and no technology exists for recovery of the methane. In the 1980s, FETC performed some of the earliest research on hydrates. Today, with new funding, FETC is leading the way once again.

Hydrates lie beneath the permafrost that covers thousands of square miles in Canada, Alaska, and Siberia. However, no human eyes had ever seen hydrates from beneath North America's surface, and very little data existed. So Mroz and the team traveled to the Canadian Far North, where several layers of methane hydrates had been inferred to exist in the frozen sediment beneath Richards Island. The inference came from logs of a test well drilled into the sands and gravels of the island, which is part of the Mackenzie River's icy delta where the river empties into the Arctic Ocean. The site is in caribou and polar bear country, at about 69° North latitude, some 3° above the Arctic Circle.

The test well, named Mallik L-38, was drilled by Imperial Oil in 1971. On the logs, petroleum scientists had spotted the telltale spikes of methane gas concentration and temperature shift that betrayed the presence of layers of hydrates—ten of them, totaling about 360 feet in thickness. They occurred between a quarter-mile and a half-mile below the surface.

(You can read more about the Mallik L-38 well. See the Geological Survey of Canada Homepage at sts.gsc.nrcan.gc.ca/page1/hydrate/hydrates.html)

New Methane Hydrates Test Well

The new test well was drilled only 100 feet from Mallik L-38 to make sure the layers of hydrates would have similar thicknesses and would be encountered at similar depths. The intent was to recover intact samples of the hydrates and to perform gas-production tests. The hope was that the frigid environment would keep the core samples frozen for study.

After several days of drilling and hauling up lengths of core, the diamond-toothed drill bit reached its target depth of over a mile below the surface. Logging instruments then were slowly drawn up the wellbore to sense methane gas, temperature, electrical, acoustic, and other parameters. Data from these instruments created a log of the sediment layers, from the bottom of the well up through the layers of hydrates to the permafrost.

Watching the videotape of the drill cores being opened, you can see the white, slushy hydrates mixed into the gravel, sand, and silt from the old river delta. The team collected samples of hydrates from the core and placed them in a dish of water, watching for telltale bubbles to rise through the water, the quickest way to detect the gas as it escapes from its icy bondage. One scientist picked up a small piece of hydrate and rolled it between his thumb and fingers. As it melted, it sputtered, fizzed, and bubbled as methane escaped into the air.

Recovered Cores are First North American Samples

Drilling of the methane hydrates test well can only be described as a struggle from start to finish. Scheduling and weather delays were followed by technical challenges and equipment problems. These were expected, as the team was testing new technology under harsh environmental conditions. This involved drilling a core a few inches in diameter through all ten hydrates layers and bringing them to the surface intact.

In the well, hydrates were encountered about a half-mile below the surface. Two stretches of core, representing layers of hydrates roughly 8 to 10 yards in vertical thickness, contained spectacular hydrates concentrations in porous sand and gravel. Each section released methane for several minutes after the cores were opened to the air. Opaque white hydrates were observed throughout several zones. Being able to witness this was remarkable, considering that the travel time to the surface was 2 to 3 hours, which is ample time for significant methane to escape the depressurized hydrates.

These samples are the first confirmed gas hydrates collected from beneath permafrost in North America. Because the goal of this research is to expand the natural gas supply, results from our research are extremely encouraging. In some samples, hydrates filled a significant part of the pore

It looks like plain ice, but it is loaded with natural gas that could fuel the future with help from FETC's technologies.

space that exists among the particles of sand and gravel. As tested in the laboratory, the maximum possible yield from pure hydrates is about 170 cubic centimeters of gas per gram of ice.

The team analyzed cores that contained permafrost and hydrates. Analysis of the cores and well logs suggests extremely high hydrates concentrations. Preliminary estimates from log data in the old Mallik L-38 well are that greater than 60-percent pore saturation occurs throughout most layers of hydrates, and in some cases nearly 100-percent saturation. Much research still lies ahead.

It is important to disseminate the data from this historic test. Team members are presenting results at an international symposium, and plans for further scientific studies are underway.

Hydrates History

Hydrates have been a laboratory curiosity since the nineteenth century. They also are a well-known problem in natural gas pipelines, where they form from moisture in the lines, creating costly icy clogs. But the vast store of hydrates beneath Earth's surface was not discovered until the 1960s, and was not considered a resource until recently.

This relative newness to scientists and the inaccessible locations of hydrates mean that the substance has been little-studied so far. However, the resource is generally accepted to be far greater than the conventional natural gas resources in sandstones and coal beds. Worldwide, proven natural gas reserves in conventional reservoirs are 5,000 trillion cubic feet (Tcf), but the hydrates resource may contain *hundreds of millions* of Tcf.

Hydrates are also extremely rich in methane. A cubic foot of hydrates, in the natural setting, can hold up to 170 cubic feet of gas. Hydrates can hold 40 to 100 times more methane than a cubic foot of the porous sandstone that forms a conventional gas reservoir. Far more gas can be recovered from a given volume of hydrates than from the same volume of conventional rock reservoir—potentially.

Furthermore, hydrates-cemented sediment creates a barrier that can trap free methane gas beneath them. This can create a "dual reservoir" of methane: the gas in the hydrates, plus the free methane beneath them. One strategy is to drill through the hydrates barrier into the free gas and harvest it while the diminishing pressure on the hydrates lets it break down to release more methane, recharging the reservoir.

Canadian sunset forms a backdrop for the Mallik 2L-38 test well north of the Arctic circle in the Northwest Territories.

Burning Dirty Sherbet

Depending on conditions, methane hydrates can resemble ice, or dirty sherbet, or frost. Hydrates are abundant not only in permafrost sediments of the Arctic, but are also widespread beneath the seafloor beyond the continental shelf, where water depth exceeds 1,000 feet. Both settings have the requisite methane source, moisture, low temperature, and high pressure needed to create methane hydrates. In sediment, hydrates act like cement to bind gravel, sand, and silt into layers that can become hundreds of feet thick.

FETC's Hydrates Research

Methane hydrates are nothing new to FETC. In 1982, FETC scientists analyzed a hydrates-bearing drill core from off the coast of Guatemala, recovered by the research vessel *Glomar Challenger.*

If technology can be developed to permit the economic production of natural gas from hydrates in great volumes, it could change the way the world uses fossil fuels. And this, of course, is why FETC is involved: as the U.S. government's première fossil-energy R&D facility, FETC is continuing to develop some of the technologies necessary to find, economically extract, transport, and use methane from hydrates.

Recognizing the promise of hydrates as a resource, DOE's budget for fiscal 1999 includes new funds for hydrates research. About $500,000 will fund FETC's mission to "establish a comprehensive interagency program to identify, characterize, and recover methane from the vast hydrates resources in both offshore and onshore (permafrost) regions." This interagency program includes FETC and the USGS (for hydrates geology), NOAA (National Oceanic and Atmospheric Administration, for ocean depth measurements), and the U.S. Naval Research Laboratory (for acoustic studies to help locate hydrates formations).

FETC researchers Rodney Malone and Bill Lawson ignite a sample of methane hydrates from a seafloor core recovered off the Guatemalan coast, part of FETC's early hydrates research conducted in the 1980s.

Once the best hydrates deposits are identified, the problems of recovering the methane and getting it to market are daunting. Releasing the methane from hydrates ice comes down to either depressurizing the substance or melting it. Trying to accomplish either beneath the seafloor or beneath permafrost will not be simple.

Developing the Hydrates Resource: Many Challenges

The USGS is estimating the methane hydrates resource of Alaska's North Slope. Of more than 400 Alaskan wells, 50 are inferred to contain hydrates, based on well logs. Many show multiple hydrates layers from 10 to 100 feet thick, as in the Mallik test well. The natural gas resource from Alaska's hydrates is estimated at over 600 Tcf (about 45 Tcf in discovered hydrates and 600 Tcf in undiscovered hydrates).

In addition to the vast Arctic hydrates formations, mapping off the South Carolina coast has disclosed large accumulations. Two areas the size of Rhode Island have very rich hydrates concentrations. The USGS estimates them to contain more than 1,300 Tcf of

Based on well logs, 50 Alaskan wells are inferred to contain hydrates.

methane (this is 70 times the entire U.S. natural gas consumption in 1989). Hydrates formations also exist off the coasts of Oregon, California, New Jersey, Alaska, the Gulf Coast states, India, Japan, Norway, and other locations.

With this wealth off our shores and in the Arctic, we must consider what it will take to commercially develop methane hydrates. How can we access hydrates that are buried under Arctic permafrost or lie beneath 1,000 feet or more of ocean? How can we extract the methane frozen in the hydrates? How can we transport the methane from such remote sites to where it is needed, thousands of miles away—pipeline it as a gas, or liquefy it first? How pure is the methane from hydrates? How reliable could the supply be? How often will we have to move the extraction equipment from a depleted site to an untapped one? And, underscoring all of these questions: what is the cost? Is methane recovery from hydrates economically feasible, or is this just an ice dream?

The Future

Methane hydrates have the potential to become a major natural gas source. The resource may also be a major player in global climate change. But our knowledge of hydrates is in its infancy, and new knowledge must be built on the work done so far by FETC, the USGS, and others. It is likely that the next generation not only will know all about methane hydrates, but may also heat their homes with its rich load of fossil energy. In the meantime, Earth is keeping its vast store of hydrates on ice.

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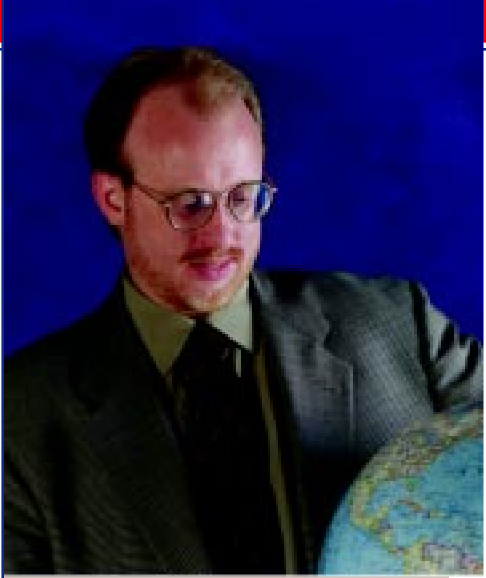

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The Americas

Choosing Energy Options

To strengthen global environmental stewardship and strategic U.S. hemispheric alliances, the Federal Energy Technology Center (FETC) is promoting clean energy technologies within the Western Hemisphere.

FETC is developing a project with the Guatemala/Central America Program (G/CAP) Office of the U.S. Agency of International Development (USAID) to demonstrate the efficacy of using landfill gas to generate electricity while controlling greenhouse gas (GHG) emissions.

Guatemala's total installed power capacity is 1,325 megawatts (MW), but only about 930 MW are operable. About 500 MW of new capacity will be needed over the next 10 years. FETC and USAID have met with officials from the Municipality of Guatemala City to explore utilizing landfill gas from El Trebol landfill to generate electricity. A preliminary estimate indicates a generation potential of 25 to 50 MW from the landfill, which is located in the center of the city. Although conventional combustion equipment may be used in the project, FETC will investigate using the landfill gas in highly efficient fuel cells or gas turbines developed under FETC-managed programs.

Greenhouse Gas Reductions

Composed primarily of methane and carbon dioxide, landfill gas contributes directly to potential global warming. In particular, methane has about 27 times the global warming effect of carbon dioxide, but receives less attention because its global emissions are much lower. Using the methane to generate power will minimize the environmental impact of the landfill emissions.

FETC is working with the USAID G/CAP office to conduct a feasibility study for a commercial power generation project at the landfill—that will generate certified GHG credits. FETC will recruit a U.S. company to enter into a joint project with the Municipality of Guatemala City.

Such cooperative efforts between countries to reduce net GHG emissions—called *activities implemented jointly* (AIJ)—hold significant potential for combating the threat of global warming and promoting sustainable development. AIJ is recognized under the U.N. Framework Convention on Climate Change, and has been a key element in the administration's strategy for mitigating global warming.

The project is being timed to coincide with the privatization of El Trebol landfill, which is owned and operated by the Municipality of Guatemala City. If successful, this waste-to-energy project will be replicated by FETC and USAID throughout the Latin American and Caribbean (LAC) Region where a number of other large landfills exist. In addition to reducing the threat of global warming, such efforts will spur U.S. technology exports to the region.

Promoting Clean Energy Options

Efficient power-generation systems based on fossil fuels and renewable energy sources are vital to diversifying, and thereby securing, a stable fuel mix in the Americas as well as minimizing the potential of global warming. A few years ago, FETC and other DOE Fossil Energy staff sat down with energy experts from a number of LAC countries as part of a Clean Energy Options (CEO) Working Group. The group drafted a *Clean Energy Technologies for the Americas Report*, released in December 1996. (The report is available on the Internet at http://146.138.65.100/abstracts/96hemiab.htm.)

The study—conceived at the 1995 Hemispheric Energy Symposium—represents 18 months of joint efforts by energy specialists from the U.S., Canada, and several democratic Latin American nations. The report describes current and developing clean-energy technologies that are on fast-track development paths in various countries in the Western Hemisphere. And the report also highlights each nation's contemporary energy mix and the prospects of diversifying its electric power-production facilities.

While the Guatemalan landfill-gas project was not one of the 12 fast-track projects identified in the report, it typifies some of the clean-energy options that various countries can pursue. The CEO Working Group is discussing an update of the fast-track project report, which will include other technology options such as landfill-gas power generation.

The CEO Working Group also developed an electronic database of the current power-generation base in the Hemisphere and projections to 2010. Government officials from most of the 34 democratic nations in the Hemisphere provided data on their countries to ensure the database's accuracy.

The database, completed late last year, contains vital information on a nation's energy profile: the fuels it is using and has used in the past; the type, size, and number of power plants in operation; and current and projected electric power demand. Based on future energy scenarios, the database can be used to project energy prices, energy supply and demand, and the impact pollution has on the environment.

This is basically an analytical tool, explains Scott Smouse, FETC's International Program Product Manager. It allows leaders of a country to quickly look at the overall impact their decisions could have on the local environment and the energy balance. The database provides information on clean-energy options, including fossil and renewable technologies, to a corner of the world where environmental regulations and control technologies are just now being put into place.

The Future?

FETC continues to participate in the CEO Working Group to promote and demonstrate clean, efficient U.S. energy technologies throughout the Hemisphere. In addition, FETC's international team is pursuing other collaborative clean-energy activities around the world.

FETC's international efforts will help bolster trade and enhance energy and environmental security. And there is little doubt that the new, clean-energy technologies in which the U.S. has invested will figure prominently.

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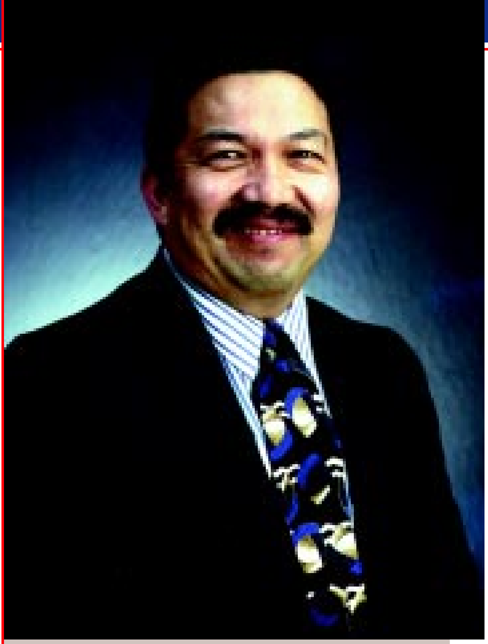

Curtis V. Nakaishi

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Recipe for Energy Savings

If you are responsible for a government facility, how will you provide services and fulfill your mission if the books don't balance? Your facility's utility bills continue to climb while your budget is shrinking.

Not only is some of your existing equipment wasting energy, there is no clear financial relief in sight to replace it. In addition, you are compelled to meet Energy Policy Act (EPACT) requirements to reduce energy consumption from 1985 levels by 20 percent in 2000 and 30 percent by 2005!

But the technical, economic, legal, and contractual maze of Energy Management takes a lot of effort and analysis—activities that your busy staff probably does not have the time to do. Consider temporarily expanding your federal staff and "borrowing" some of FETC's energy experts.

FETC provides our federal government colleagues with comprehensive technical, business, and economic services to satisfy their energy savings requirements. We understand advanced electric-generating and natural-gas technologies, and we have developed our own Energy Management Plan.

Our recipe includes key ingredients and key instructions; you can choose to follow part or all of the recipe to meet your needs.

Strategize

Devise **a Site Energy Strategy:** A Site Energy Strategy ensures that the best technical options have been explored and your special energy and environmental needs are fully addressed.

FETC will provide unbiased, objective, technical analyses to answer your critical questions:

- What energy conservation measures (ECMs) should be pursued first?
- How can energy management activities be coordinated with plans for facility expansion or improvement?
- How can your site improve its environmental performance?
- Should you switch fuels?
- Does your power quality need to be improved?
- Do you have adequate backup power capacity?
- Is self-generation of electricity feasible, both technically and economically?
- If so, which power-generation technologies would work best?
- Is cogeneration attractive?

Energy Savings Recipe

Key Ingredients:

ECM—energy conservation measure

EPACT—Energy Policy Act

ESP—energy savings performer

ESPC—energy savings performance contract

RESEP—Regional Environmental and Sustainable Energy Partnership

Key Instructions:

Strategize *Devise* a site energy strategy, *Conduct* a preliminary energy survey, *Assess* potential ECMs

Measure *Determine* energy-usage baseline, *Prepare* a technical data package, *Measure* and *Verify*

Manage *Select* an option, *Administer* the agreement, *Manage* the project

We consider the whole picture. We have a unique understanding of advanced technologies in environmental management, emissions control, power generation, and innovative ECMs from both sides—through experimental validation and experience in project management.

***Conduct* a Preliminary Energy Survey:** FETC will conduct a preliminary survey of your site to gather the basic information needed to define your energy management program.

Typically, the survey will focus on the following areas: heating/ventilating/air-conditioning systems, lighting, motors, and water systems.

***Assess* Potential ECMs:** FETC will perform a detailed technical and economic assessment of your most promising ECMs. We will use building and systems simulation software to evaluate your potential cost savings and identify short- and long-term energy management goals. Many ECMs are interactive, and our advanced tools can account for this interaction.

The assessment will recommend options and estimate the energy cost savings and simple payback period for each option. The assessment can be used later to judge the reasonableness and innovation of ECMs proposed by energy savings performers (ESPs).

Measure

***Determine* Energy Usage Baseline:** A facility's baseline energy usage is the foundation upon which future energy savings—and thus payments—are calculated. You need to define your energy-usage baseline as soon as possible so you can accurately calculate future energy savings.

FETC has no conflict of interest, so we can define the critical baseline you and your ESP use to calculate future energy savings. Using your energy-usage baseline, FETC will benchmark your usage against that of similar facilities nationwide.

FETC will divide your facility's total energy usage into convenient categories for calculating energy savings. Wherever existing metering is inadequate to characterize energy usage in a key area, FETC will recommend temporary or permanent new metering.

***Prepare* a Technical Data Package:** FETC will use information from the preliminary energy survey, assessment of potential ECMs, your energy-usage baseline, and your needs and expectations to prepare a technical data package. Potential ESPs will use the package to submit proposals.

The package could define a limited-scope project, which simplifies the evaluation of competitive proposals and allows you to choose the best ESP. A robust technical data package also gives the selected ESP a significant head start in understanding your facility from an energy systems perspective. This saves you both time and money. FETC will ensure that the project scope defined in the technical data package does not inhibit the accomplishment of additional projects.

***Measure* and *Verify*:** ESPs are normally responsible for determining energy performance, and consequently, how much funding they recover. FETC will provide an objective check and validation of the energy performance.

FETC uses spot follow-up surveys, performed at least annually, to verify the measurements and reasonableness of the cost savings, based on the predetermined energy-usage baseline.

Manage

***Select* an Option:** FETC will help you evaluate your contracting alternatives by presenting the advantages and disadvantages of choosing:

- Energy Savings Performance Contracts (ESPCs),
- Utility Incentive Programs, or
- Competing Self-Financed ECMs.

Federal agencies can enter into ESPCs to implement energy conservation projects. The advantage to your facility is that the installation, commissioning, maintenance, and operation of the ECMs, as well as the associated training, are initially paid for by the selected ESP.

The ESP is paid through a share of the energy cost savings. At the end of the contract, the government facility retains all subsequent savings and capital equipment.

The government facility saves energy and improves its infrastructure without any additional funding, ESPs earn a profit from energy cost savings, manufacturers of energy-efficient equipment realize product sales, utilities are not required to add capacity, and national energy security is strengthened through more efficient use of energy resources.

Everybody wins!

FETC will also use its technical and procurement staff to help you evaluate and select the best ESP. For example, prior to the request for proposals, FETC will help you prepare scoring forms and criteria for evaluating proposals, references, and oral presentations.

***Administer* the Agreement:** FETC will use its procurement authority to place the agreement or work with your procurement group. We will use our extensive and expert contract administration capability, and our financial and legal expertise, to place and oversee the procurement, financial, and legal aspects of your energy-savings performance project.

***Manage* the Project:** FETC will serve as your extended technical staff to verify that work is performed to specifications and that the equipment is properly installed and commissioned. FETC also will review project status and cost reports and take corrective action if necessary.

RESEP

FETC's recipe for energy savings is also RESEP.

The Regional Environmental and Sustainable Energy Partnership or RESEP (pronounced recipe) region is Western Pennsylvania, Eastern Ohio, Western Maryland, and North Central West Virginia.

FETC is stimulating the energy and environmental capabilities of the RESEP region by encouraging partnerships between regional government, industry, and academic organizations. Such partnerships can yield significant energy savings.

Historically, the focus of the RESEP region is energy—it is rich in fossil fuels; it is the location of the nation's first power plant; and America's steel, iron, coke, and glass industries all trace their roots to the region.

The intention is to establish the region as an internationally renowned hub for the research and development (R&D), design, manufacturing, finance, sales, operation, and export of advanced products, technologies, and services in the energy and environment sectors.

FETC acts as the coordinator of the RESEP, and FETC's recipe for energy savings in the RESEP is to expand the region's economic basis to include:

1. Energy vendors who will upgrade federal facilities.
2. R&D organizations such as universities who will design innovative ECMs.
3. Other organizations including local and state governments who will conduct similar energy-savings efforts.

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The Greenhouse Effect: Its Cause

Your car becomes an oven on sunny summer days if you roll the windows up tight. Why?

Sunlight's short wavelengths pass easily through window glass. When this light energy strikes your car's opaque interior, it is absorbed and reradiated as heat energy. The heat tries to pass back through the glass, but its longer wavelengths (infrared) are blocked by the glass. The trapped heat energy builds up and the temperature skyrockets, making your car a "solar oven."

This phenomenon is put to work in greenhouses, giving it the name "greenhouse effect."

Similarly, sunlight passes through Earth's atmosphere to the surface, where it is converted to heat. As the heat energy tries to radiate back into space through the atmosphere, it encounters various gases. Over 99 percent of the gases let the heat energy pass unimpeded.

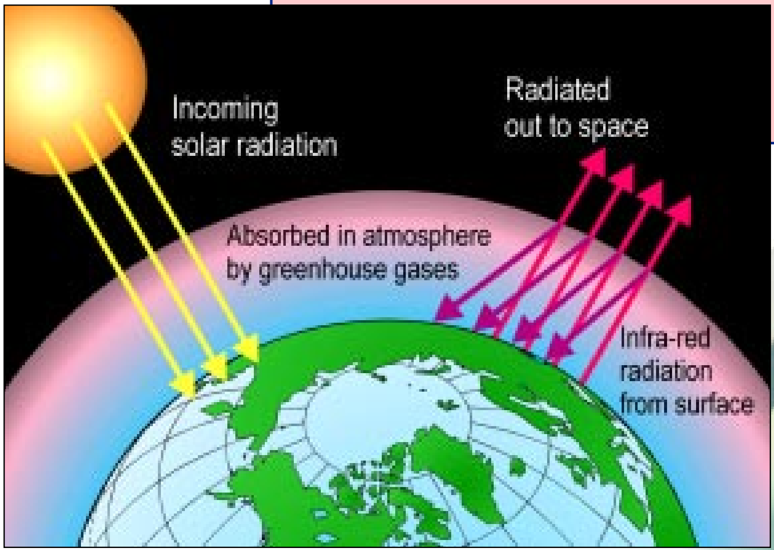
But a tiny fraction, the *greenhouse gases (GHGs),* have molecules the right size and shape to absorb and retain the heat. These gases include water vapor, carbon dioxide (CO_2), methane, and nitrous oxide. The retained heat builds up, causing a global-scale greenhouse effect and thus warming Earth's surface.

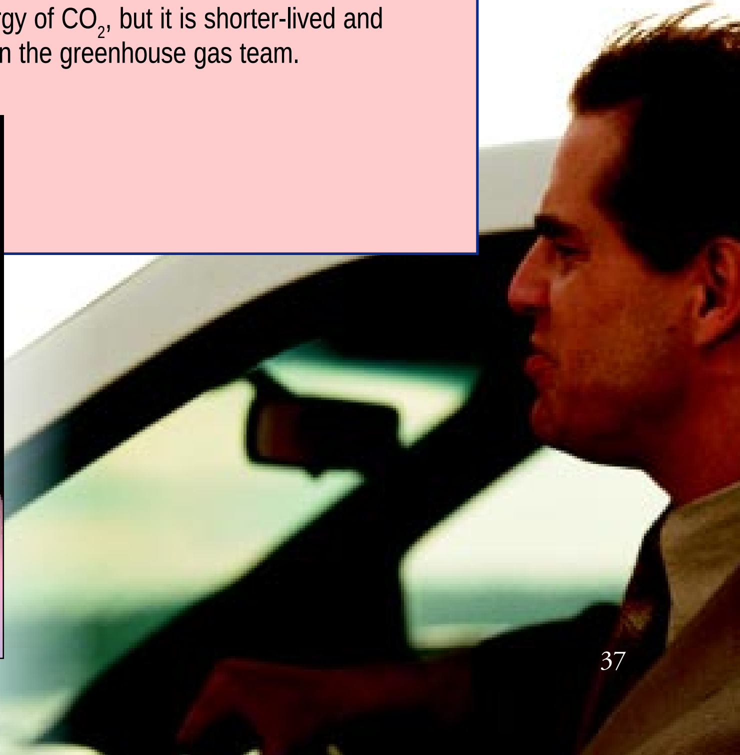
The Greenhouse Gases

The most important human-generated GHGs are ***carbon dioxide*** (CO_2) and ***methane*** (CH_4), which is the chief component of natural gas. Less significant GHGs are nitrous oxide (N_2O), ozone (O_3), and some refrigerants (chlorofluorocarbons or CFCs like Freon™).

Water vapor actually is the most potent and variable greenhouse gas, but human-generated quantities are insignificant compared to natural humidity. Thus, the fossil-energy programs at the Federal Energy Technology Center (FETC) focus on CO_2 and methane.

Most human-generated CO_2 comes from combustion of coal, oil, and natural gas, which collectively contribute 80 percent of the increase in human-generated GHG. Human-released methane also comes from leaks in natural-gas plants and pipelines, and from coal seams that are disrupted by mining. Methane absorbs 27 times the heat energy of CO_2, but it is shorter-lived and scarcer, and thus is a less burly player on the greenhouse gas team.





The Greenhouse Effect: Its Results

Earth's natural greenhouse effect is delicately balanced, giving us livable temperatures worldwide. But we are rightly concerned about possible change, either hotter or cooler:

- *A reduced* greenhouse gas (GHG) concentration in the atmosphere would diminish the greenhouse effect, causing global cooling. Sufficient cooling would freeze water into expanded glaciers. This would lower the sea level, create a soaring demand for fossil fuels for heating, and would shift weather patterns.

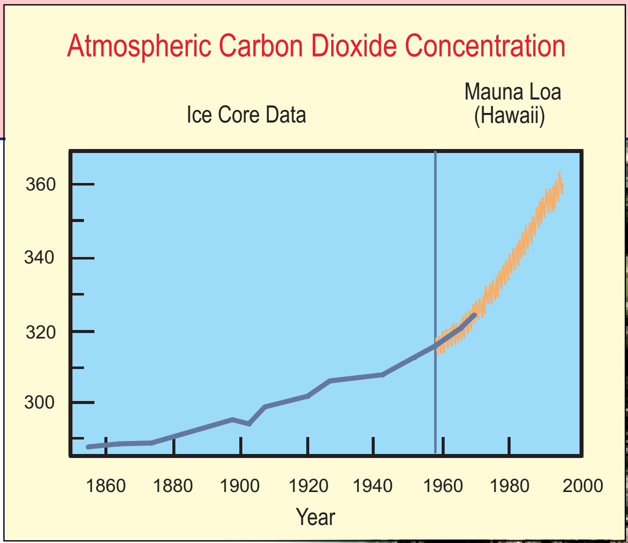
- *An increased* GHG concentration would increase the greenhouse effect, warming Earth's atmosphere. Just a few degrees increase could partially melt glaciers and ice caps. Meltwater running into the ocean would raise the sea level worldwide, slowly (over years) drowning coastal cities and lowland areas like Florida and Bangladesh. In fact, sea level has slowly risen 4 to 8 inches worldwide during the past century, evidence of warming. Sea level could rise about 3 feet by the year 2100, although this is difficult to calculate. Warming also would alter regional weather, disrupting agriculture—which would mean serious economic and political disruption.

There is little question that human activity is altering the atmosphere. Records kept since 1850 indicate a 30-percent increase in CO_2, coinciding with worldwide industrialization achieved through fossil-fuel combustion (coal, oil, and gas). The CO_2 increase is certain; it is the consequences that are being debated.

The worldwide warming measured during the past 100 years—about 1°F—sounds tiny, but on a global scale, it becomes significant. This increase is small enough to fall within normal climatic variation, which has included alternating frigid times (ice ages) and warmer interglacial periods (like today's climate) for at least the past 200,000 years. And this highlights a frustration for scientists: we have too little data covering too short a period.

But rising sea levels, retreating glaciers, melting permafrost in the Arctic, and migration of animals and plants into regions that formerly were too cold for them appear to support predictions of greenhouse warming.

In 1995, more than 2,000 climate scientists concluded that Earth's atmosphere is warming and that the "balance of evidence suggests a discernible human influence" on climate.



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